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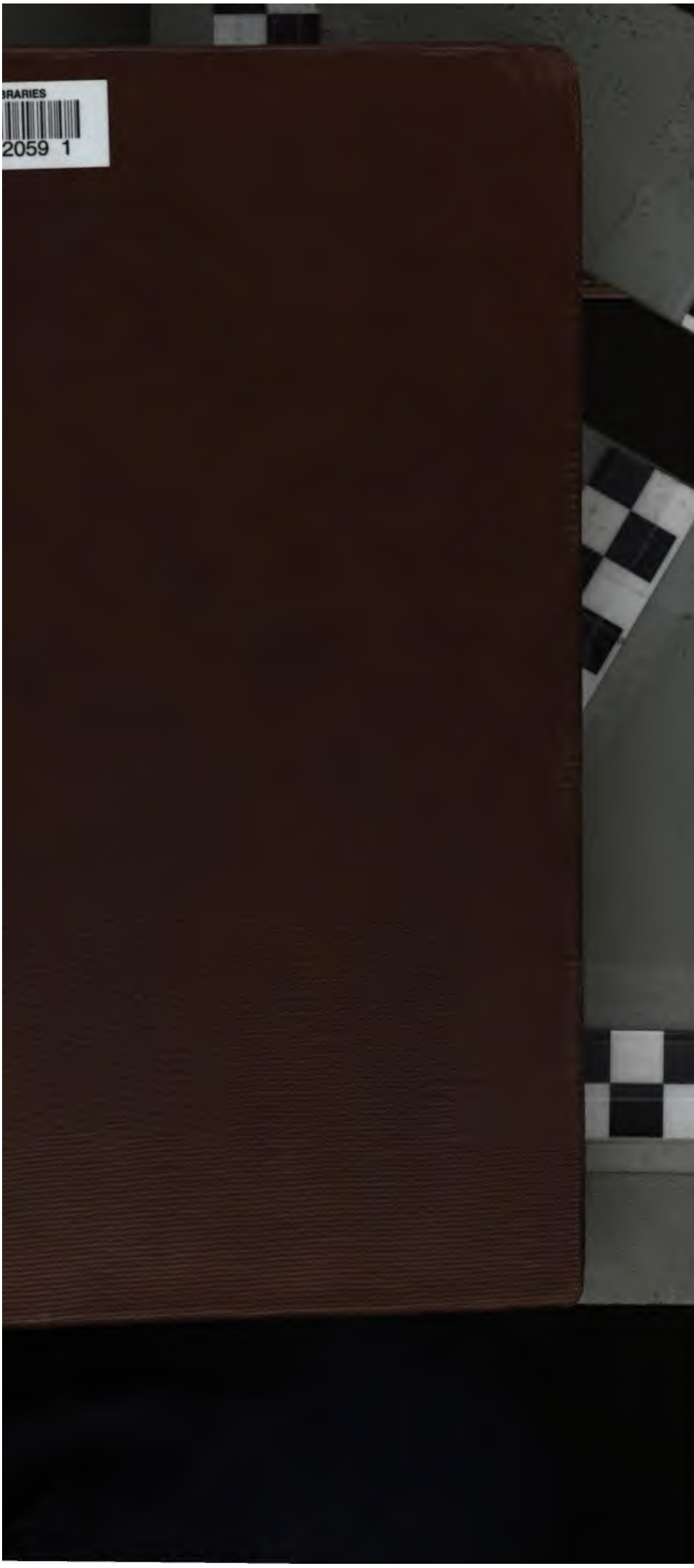
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BUILDING STONES AND CLAY-PRODUCTS

A HANDBOOK FOR ARCHITECTS

BY

HEINRICH RIES, PH.D.

Professor of Economic Geology in Cornell University; Fellow, Geological Society of America; Member, American Institute of Mining Engineers, Canadian Mining Institute, American Society for Testing Materials, American Ceramic Society, English Ceramic Society

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PREFACE

THAT at least an elementary knowledge of the subject of building stones and clay products is of importance to the architect few people will deny, since familiarity with their properties, durability, and, in the case of clay products, their methods of manufacture will enable him to select and use these materials more intelligently.

At the same time, the preparation of an elementary work on the subject is not free from difficulties, for the reason that most architects have but a limited knowledge of geology and ceramic technology. The author has, therefore, attempted to state facts and explanations as simply as possible, and as a further aid in this direction has included a glossary at the end of the book.

The general arrangement of the book follows the course of lectures given each year to the students in the College of Architecture of Cornell University, and it has been the encouraging reception which these received that has led the author to give them to the public.

The work is not intended as an exhaustive treatise, but, in stead, aims to give simply the fundamentally important facts. It is therefore, beyond the scope of the book to take up any but the more important occurrences of building stone, and those who desire detailed information on this point will consult our standard American work, "Stones for Building and Decoration" by G. P. Merrill.

Since the architect often desires to know how extensively and for what purposes the different building stones have been used, an attempt has been made to give a list of structures in which the more important ones at least have been placed.

The author wishes to acknowledge here assistance and advice received from many persons in the preparation of the work

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HEINRICH RIES.

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CONTENTS.

PAGE

PREFACE iii

CONTENTS v

LIST OF PLATES xi

LIST OF FIGURES xv

INDEX 401

PART I.

BUILDING STONES.

CHAPTER I.

ROCK MINERALS AND ROCKS 3

Introduction, 3; Rock-forming minerals, 5; Physical properties, 5; Hardness, 6; Cleavage, 6; Lustre, 6; Form, 6; Quartz, 7; Feldspars, 7; Orthoclase, 7; Plagioclase feldspar, 7; Micas, 8; Amphibole, 9; Hornblende, 9; Tremolite, 9; Pyroxene, 9; Calcite, 10; Aragonite, 10; Dolomite, 10; Gypsum, 10; Serpentine, 11; Talc or steatite, 11; Olivine, 11; Garnet, 11; Chlorite, 11; Pyrite or iron pyrite, 12; Magnetite, 12; Limonite, 12; Rocks, 12; Igneous rocks, 12; Granite, 18; Pegmatite, 18; Syenite, 23; Diorite, 23; Gabbro, 23; Peridotite, 23; Pyroxenite, 23; Granite porphyry, 23; Syenite porphyry, 23; Diorite porphyry, 24; Felsite, 24; Basalt, 24; Stratified rocks, 24; Sandstone, 29; Conglomerate, 29; Shale, 29; Limestone, 29; Chalk, 30; Calcareous tufa, 30; Travertine, 30; Onyx, 30; Coquina, 30; Dolomite, 30; Metamorphic rocks, 30; Quartzite, 30; Slate, 30; Phyllite, 31; Marble, 31; Ophicalcite, 31; Gneiss, 31; Schist, 31; Structural features affecting quarrying, 31; Bedding, 32; Joints, 32.

CHAPTER II.

PROPERTIES OF BUILDING STONE 36

Texture, 36; Hardness, 36; Color, 37; Variation in color, 38; Change of color, 38; Polish, 40; Specific gravity and porosity, 40; Absorption, 44; Quarry water, 44; Crushing strength, 44; Transverse strength, 51; Frost resistance, 54; Fire resistance, 55; Expansion and contraction of building stones, 69; Abrasive resistance, 70; Discoloration, 73; Effect of sulphurous acid gas and dilute sulphuric acid, 74; Effect of carbonic acid gas, 74; Chemical composition of building stones, 75; Weathering and decay of building stones, 75; Disintegration, 76; Temperature

PAGE

changes, or heat and cold, 76; Expansion caused by freezing, 79; Abrasive action, 80; Plant action, 80; Careless methods of extraction and working, 80; Decomposition, 81; Sulphurous and sulphuric acids, 85; Hardening of stone on exposure, 85; Life of a building stone, 86; Sap, 87; Literature on building stones, 87; General works, 87; Serials, 88; Special papers, 88.

CHAPTER III.

IGNEOUS ROCKS (CHIEFLY GRANITES) AND GNEISSES 93

Characteristics of granites, 94; Elasticity, 94; Flexibility, 94; Expansibility, 95; Porosity, 95; Fire resistance, 95; Chemical composition, 95; Classification, 95; Structure of granites, 96; Sheets or beds, 96; Knots, 96; Inclusions, 99; Dikes, 99; Black granites, 99; Tests of granite, 99; Uses of granite, 105; Distribution of igneous rocks (chiefly granites) and gneisses in the United States, 105; Eastern belt, 105; Maine, 106; North Jay, 106; Crotch Island, 106; Hallowell, 106; Vinalhaven and Hurricane Islands, 109; Red Beach, 109; Addison, 109; Jonesboro, 110; Blue Hill, 110; Brookville, 110; Dix Island, 110; Clark's Island, 110; Machias, 110; Pleasant River, 110; Stonington, 110; Classification of Maine granites, 110; New Hampshire, 111; Concord, 111; Milford, 112; Conway, 112; Auburn, 112; Troy, 112; Fitzwilliam, 112; Mascoma granite, near Enfield, 113; Classification of New Hampshire granites, 113; Vermont, 116; Hardwick, 116; Barre, 116; Bethel, 116; Woodbury, 119; Windsor, 119; Massachusetts, 120; Milford, 120; Rockport, 120; Chester, 125; Quincy, 125; Classification of Massachusetts granites, 125; Rhode Island, 128; Westerly, 128; Connecticut, 128; Branford township, 131; Greenwich, 131; Waterford township, 131; Millstone, 131; Groton, 132; Market price of granites, 136; New York, 137; New Jersey, 137; Pompton pink granite, 138; Dover light gray granite gneiss, 138; Cranberry Lake white granite gneiss, 138; German Valley gray granite, 138; Trap rock, 138; Maryland, 138; Granites, 141; Port Deposit, 141; Ellicott City, 141; Guilford, 141; Woodstock, 141; Frenchtown area, 142; Gneisses, 142; Virginia, 142; Petersburg area, 142; Richmond area, 142; Fredericksburg area, 145; Other localities, 145; North Carolina, 145; Even granular granites, 146; Coastal plain, 146; Piedmont plateau region, 146; Greystone, 149; Raleigh, 149; Wise, 149; Rowan County, 149; Mount Airy, 149; Porphyritic granites, 149; Miscellaneous rocks, 150; South Carolina, 150; Heath Springs, 153; Columbia, 153; Georgia, 154; Elberton-Ogelsby-Lexington area, 154; Lithonia-Conyers-Lawrenceville area, 154; Fairburn-Newman-Greenville area, 154; Stone Mountain area, 155; Sparta area, 155; Alabama, 155; Wisconsin-Minnesota area, 155; Wisconsin, 155; Montello, 155; Berlin, 156; Warren, 156; Waupaca, 156; Wausau, 157; Amberg, 157; Minnesota, 157; Southwestern area, 158; Missouri, 158; Graniteville, 158; Knob Lick, 158; Arkansas, 159; Oklahoma, 159; Wichita Mountains, 159; Arbuckle Mountains, 159; Texas, 160; Cordilleran area, 160; Montana, 160; Colorado, 160; California, 161; Rocklin, 161; Raymond, 161; Riverside County, 161; Oregon, 161.

CHAPTER IV.

PAGE
SANDSTONES 162

Texture, 162; Hardness, 162; Color, 163; Absorption, 163; Crushing strength, 163; Weathering qualities, 165; Fire resistance, 165; Varieties of sandstone, 165; Arkose, 165; Bluestone, 165; Brownstone, 165; Calcareous sandstone, 165; Ferruginous sandstone, 166; Flagstone, 166; Freestone, 166; Graywacke, 166; Quartzite, 166; Distribution of sandstones and quartzites, 166; New England States, 166; Eastern Atlantic States, 167; New York, 167; Medina sandstone, 167; Potsdam sandstone, 167; Warsaw blue stone, 168; Hudson River bluestone, 168; New Jersey, 168; Pennsylvania, 169; Maryland, 169; Virginia, 170; West Virginia, 170; Alabama, 170; Central States, 170; Ohio, 170; Indiana, 173; Illinois, 174; Michigan, 174; Wisconsin, 174; Minnesota, 175; Missouri, 176; Arkansas, 176; Western States, 176; Montana, 176; Colorado, 176; Washington, 177; California, 177.

CHAPTER V.

LIMESTONES AND MARBLES 178

Limestones and dolomites, 178; Color, 178; Hardness, 178; Texture, 178; Absorption, 181; Weathering qualities, 181; Crushing strength, 181; Fire resistance, 181; Tests of limestone, 181; Chemical composition, 183; Varieties of limestone and dolomite, 183; Chalk, 183; Coquina, 183; Dolomite, 183; Fossiliferous limestone, 183; Hydraulic limestone, 183; Lithographic limestone, 183; Magnesian or dolomitic limestone, 184; Marble, 184; Oölitic limestone, 184; Travertine, calcareous tufa, or calc sinter, 184; Distribution of limestone in the United States, 184; New York, 189; New Jersey, 189; Pennsylvania, 189; Maryland, 190; Virginia, 190; West Virginia, 190; Alabama, 190; Florida, 191; Illinois, 191; Indiana, 191; Kentucky, 192; Ohio, 192; Wisconsin, 192; Minnesota, 195; Missouri, 196; Iowa, 196; Kansas, 196; Texas, 197; Cordilleran region, 197; Marbles, 197; Mineral composition, 197; Color, 198; Texture, 198; Weathering qualities, 201; Absorption, 201; Crushing and transverse strength, 201; Uses of marbles, 201; Distribution of marbles in the United States, 202; Vermont, 202; Light marbles, 207; Dark marbles, 213; Ornamental or fancy marbles, 213; Champlain marbles, 214; Massachusetts, 215; Connecticut, 215; New York, 215; Pennsylvania, 216; Maryland, 216; Virginia, 217; North Carolina, 217; Tennessee, 218; Georgia, 218; Alabama, 223; Missouri, 223; Colorado, 223; Arizona, 223; California, 224.

CHAPTER VI.

SLATE 225

Classification of slate, 225; Properties of slate, 229; Sonorousness, 229; Cleavability, 229; Cross-fracture, 229; Character of cleavage surface, 229; Lime, 229; Color and discoloration, 229; Presence of clay, 229; Presence of marcasite, 230; Strength, 230; Toughness or elasticity, 230; Density or specific gravity, 230; Abrasive resistance, 230; Corrodibility, 230; Electrical resistance, 230; Tests of slates, 233; Price of slate, 235; Quarrying, 236; Distribution of slate in the United States, 236; Maine,

PAGE

237; Vermont, 237; Sea green slate, 237; Unfading green slate, 237; Purple and variegated, 237; New York, 238; New Jersey, 238; Pennsylvania, 238; Maryland, 241; West Virginia, 241; Virginia, 241; Georgia, 241; Arkansas, 241; California, 242.

CHAPTER VII.

SERPENTINE 243

Distribution of serpentine in the United States, 243; Massachusetts, 244; Vermont, 244; New York, 244; New Jersey, 244; Pennsylvania, 244; Maryland, 249; Georgia, 249; California, 249; Washington, 249; Onyx marbles, 249.

PART II.

CLAY PRODUCTS.

CHAPTER VIII.

PROPERTIES OF CLAY 253

Physical properties, 253; Plasticity, 253; Shrinkage, 254; Tensile strength, 255; Fusibility, 255; Chemical properties, 256; Analyses of clay, 258.

CHAPTER IX.

BUILDING BRICK 259

Kinds of brick, 259; Raw materials used for building brick, 263; Common brick, 263; Pressed brick, 263; Enameled brick, 264; Methods of brick manufacture, 264; Preparation, 264; Molding, 265; Soft mud process, 265; Stiff mud process, 269; Dry press and semi-dry press process, 275; Re-pressing, 276; Drying, 276; Burning, 279; Comparison of brick made by different processes, 283; Testing of brick, 284; Crushing test, 284; Transverse test, 294; Absorption test, 296; Rate of absorption, 300; Permeability, 301; Relation between crushing strength, transverse strength, and absorption, 302; Fire tests, 302; Coefficient of expansion, 305; Frost test, 305; Proposed standard specifications for building brick, 307; Selection of samples, 307; Transverse test, 307; Compression test, 308; Absorption test, 308; Freezing and thawing tests, 308; Requirements, 309; Specific gravity, 309; Efflorescence or scum on bricks, 312; Testing bricks for scumming power, 313; Requisite qualities of brick, 314; Common brick, 314; Pressed brick, 314; Enameled brick, 317.

CHAPTER X.

ARCHITECTURAL TERRA COTTA 320

Definition, 320; Raw materials, 320; Method of manufacture, 320; Properties of terra cotta, 324; Testing terra cotta, 324; Terra cotta scum, 328; Fire-resisting properties, 328.

CHAPTER XI.

HOLLOW-WARE FOR STRUCTURAL WORK AND FIREPROOFING 333

Types of hollow-ware, 333; Raw materials and manufacture, 333; Fireproofing, 334; Furring blocks, 338; Hollow block and brick, 338; Tests of hollow blocks, 340; Fire tests, 346.

CHAPTER XII.

PAGE
ROOFING TILE 349
Shingle tile, 349; Old Spanish, Normal, Mexican, Mission or Roman tile, 350; Modern Spanish or S tiles, 350; Interlocking tile, 351; Materials and manufacture, 352; Porosity of roofing tiles, 352; Requisite characters of roofing tile, 359; Tests of roofing tile, 359; Miscellaneous clay slabs, used for roofing purposes, 360; Special shapes, 360.

CHAPTER XIII.

WALL AND FLOOR TILE 363
Manufacture of wall tile, 363; Properties of floor tile, 365; Method of manufacture, 366; Tests of wall tile, 369; Tests of floor tile, 369.

CHAPTER XIV.

SEWER PIPE AND SANITARY WARE 372
Sewer pipe, 372; Raw materials, 372; Manufacture, 372; Requisite qualities, 374; Strength, 374; Durability, 377; Serviceability, 377; Specifications, 377; Iowa standard specifications for drain tile and sewer pipe, 379; Absorption tests, 379; Bearing strength, 380; Computing the Modulus of Rupture, 381; Other proposed standard tests, 382; Miscellaneous tests, 384; Other hollow shapes, 385; Sewer blocks, 386; Sanitary ware, 388; Vitreous ware, 388; Solid porcelain, 388; Raw materials, 388; Manufacture, 388; Properties of sanitary ware, 388; Glossary, 390.

LIST OF PLATES

Plate		Page
I.	A small fine-grained dike of dark diabase cutting a lighter colored syenite	13
II.	A volcanic rock, trachyte, showing porphyritic texture	15
III.	Fig. 1. Moderately fine-grained granite, Hallowell, Me.	19
	Fig. 2. Very coarse-grained granite, St. Cloud, Minn.	19
IV.	Coarse-grained somewhat porphyritic granite from Crotch Island, Me.	21
V.	Pegmatite, showing coarse-grained texture	25
VI.	Fig. 1. View in a limestone quarry showing the horizontal stratification planes and vertical joint planes	27
	Fig. 2. General view of a limestone quarry showing stratified character of the rock	27
VII.	Biotite gneiss, showing characteristic banded structure of this rock	33
VIII.	Fig. 1. Gray marble, Gouverneur, N. Y., showing contrast between tooled and polished surfaces	41
	Fig. 2. Gabbro from Keeseville, N. Y., showing contrast between tooled and polished surfaces	41
IX.	Fig. 1. Photomicrograph of a section of granite	45
	Fig. 2. Photomicrograph of a section of diabase	45
X.	Photomicrograph of a section of quartzitic sandstone	47
XI.	Fire tests on 3-in. cubes of sandstones from Pleasantdale, N. J.	57
XII.	Fire tests on 3-in. cubes of limestone, Newton, N. J.	59
XIII.	Fire test of 3-in. cubes of gneiss, Mt. Arlington, N. J.	61
XIV.	Fire tests of 3-in. cubes of sandstone, Warsaw, N. Y.	63
XV.	Fire tests of 3-in. cubes of diabase, Lambertville, N. J.	65
XVI.	Results of abrasion tests with sand blast	71
XVII.	Fig. 1. Weathering of red sandstone, Denver, Col.	77
	Fig. 2. Weathered sandstone, second story County Court House, Denver, Col.	77
XVIII.	Scum of soluble salts, which has caused surface disintegration of sandstone	83
XIX.	Church in Mexico City constructed of volcanic tuff	91
XX.	Fig. 1. Granite quarry, Hardwick, Vt.	97
	Fig. 2. Granite quarry at North Jay, Me.	97
XXI.	Map showing distribution of igneous rocks and gneisses in the United States	102
XXII.	Cleveland Trust Company, Cleveland, O., constructed of North Jay, Me., granite	107
XXIII.	Map of Vermont showing granite centers and prospects	117

PLATE		PAGE
XXIV.	Map of Massachusetts showing quarry centers	121
XXV.	Fig. 1. Milford, Mass., granite showing speckled appearance, caused by biotite scales against lighter background of quartz and feldspar	123
	Fig. 2. Battle monument on Lookout Mountain, Chattanooga, Tenn., constructed of Milford pink granite	123
XXVI.	Battle monument, West Point, N. Y., polished shaft of Branford granite, 41 ft. 6 in. long and 6 ft. diameter	129
XXVII.	Map of Maryland showing distribution of granite quarries and granite and gneiss areas	137
XXVIII.	Fig. 1. Port deposit, Maryland, gneissic-granite with face cut at right angles to banding	143
	Fig. 2. Port Deposit, Maryland, gneissic-granite with face cut parallel to the banding	143
XXIX.	Fig. 1. Leopardite from North Carolina	151
	Fig. 2. Orbicular gabbro from North Carolina	151
XXX.	U. S. Post Office, Toledo, O., constructed of Berea sandstone	171
XXXI.	Fig. 1. Limestone showing dark flint nodules	179
	Fig. 2. Tremolite in dolomitic marble	179
XXXII.	Map showing limestone areas of United States	186
XXXIII.	Statue of Labor, cut in "Old Hoosier" Light Blue Bedford limestone for City Investment Building, New York City	193
XXXIV.	A decorative marble showing a brecciated structure	199
XXXV.	Interior of Harris County Court House, Houston, Texas, showing Creole matched marble	203
XXXVI.	Fig. 1. White marble, Vermont	205
	Fig. 2. Gray marble, Vermont	205
XXXVII.	Fig. 1. Quarries in Travertine near Tivoli, Italy	209
	Fig. 2. Quarry of Vermont Marble Company, Proctor, Vt.	209
XXXVIII.	Kimball monument, Chicago, Ill., done in Vermont white marble	211
XXXIX.	Monolith of Georgia marble, 27 ft. 2 in. by 4 ft. 4 in. by 4 ft. 3 in., weight 50 tons	219
XL.	Slabs of Alabama marble showing variation from pure white to those which are clouded and streaked with mica	221
XLI.	Fig. 1. Slate quarry, Penrhyn, Pa.	227
	Fig. 2. Splitting slate	227
XLII.	Map showing distribution of slate in the United States	239
XLIII.	Serpentine pedestal, Charlottesville, Va.	245
XLIV.	Serpentine from Roxbury, Vt.	247
XLV.	Fig. 1. Ornamental dry-pressed brick	261
	Fig. 2. Tapestry brick	261
XLVI.	Fig. 1. Common red soft-mud brick	267
	Fig. 2. A common soft-mud brick	267
XLVII.	Section of stiff-mud brick showing laminations	271
XLVIII.	Dry-press brick machine	273
XLIX.	Fig. 1. Common brick split by lime pebbles	277
	Fig. 2. Repressed brick	277

PLATE		PAGE
L.	Fig. 1. Setting brick for a scove kiln	281
	Fig. 2. Down-draft kilns used for burning sewer pipe	281
LI.	Brickotta, a style of ornamental brickwork	315
LII.	Terra cotta panel used in construction of State Education Building, Albany, N. Y.	321
LIII.	Terra cotta panel, Rice Hotel, Houston, Tex	325
LIV.	Interior of Railway Exchange Building, Chicago, Ill.	329
LV.	Flat arch of fireproofing	335
LVI.	Regular and special shapes of Spanish interlocking tile	353
LVII.	Fig. 1. Interlocking shingle tile showing obverse (A) and reverse (B) side	357
	Fig. 2. Molding 30-inch sewer pipe in pipe press	357
LVIII.	Encaustic tile	367
LIX.	Sewer pipe and fittings	375

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PART I.

BUILDING STONES.

BUILDING STONES AND CLAY-PRODUCTS.

CHAPTER I.

ROCK MINERALS AND ROCKS.

INTRODUCTION.

UNDER the term Building Stones are included all those rocks which are employed for ordinary masonry construction, such as walls and foundations, for ornamentation, roofing and flagging.

Many different stones are used for structural work, and, owing to the abundance of these in nearly all parts of the United States, as well as the growing demand for this class of building material, the industry has assumed proportions of considerable size.

The total quantity of stone quarried annually in the United States is large, but all of it is not employed for structural work. An attempt has been made, however, to separate the value of that so used from that consumed in other industries with the following results, the figures being taken from the 1910 report on Mineral Resources, issued by the United States Geological Survey.

APPROXIMATE VALUE OF BUILDING STONE PRODUCED IN 1910.

Granites	$10,325,874
Trap rock	87,832
Sandstone	2,272,024
Bluestone	518,660
Limestone	5,272,024
Marble	8,980,240
	$27,456,654

Practically every state produces some building stone, and many quarries are operated only for local use, partly because the weight of stone prohibits long hauls unless the material is of high grade.

By far the larger part of the building stone quarried is for ordinary dimensional work and may be sold in the rough to be dressed later. This applies chiefly to granite, sandstone, limestone and trap.

For ornamental work, and this calls for a considerable quantity of stone, the material has to meet varying requirements. In the first place it should lend itself to carving, and that some stones serve this purpose well is shown by the many intricate and beautiful designs on buildings and monuments. For monumental work, also, and decorative work, a highly polished surface is often wanted, and the granites, marbles and serpentines are usually found well adapted to this need.

Inscriptional work necessitates the selection of a stone that will give good contrast between the cut and polished surface, a character found in many of the darker granites and marbles.

In considering the selection of a building stone, the architect is usually guided either by cost or decorative value, the durability or weather-resisting qualities of the material being sometimes overlooked. The latter is a serious neglect if the stone is to be employed for exterior work in a severe climate.

Most of the building stone employed for constructional work in this country is from domestic sources, and not a little decorative stone is also obtained here; but large quantities of variegated marble for ornamental purposes, and even some other kinds of stone, are imported from foreign countries.

This can hardly be due entirely to the non-existence of such materials in the United States, but rather perhaps to the reluctance of American quarrymen to incur the risk and expense of placing a new stone on the market in competition with the foreign ones already so widely used. The factors which may be said to influence the selection of a building stone, arranged in the order of importance apparently assigned to them by many, are cost, color, fashion and durability.

The cost will naturally be a dominant factor in the selection of a stone, and depends on its location, ease of quarrying, dressing and beauty.

Color often exercises a determining influence, and this, combined with other considerations, sometimes starts a fashion which leads to the widespread use of certain stones. An excellent illustration of this was the selection, for many years, of the Connecticut brownstone in many eastern cities. More recently Indiana limestone and Ohio sandstone have met the popular fancy, and these two are now used in vast quantities.

Durability is often apparently given little consideration where a stone of high decorative character is sought, although it should in every instance be a factor of primary importance.

A study of the properties of building stones can hardly be taken up without some knowledge of their mineral constituents, or at least the common minerals which occur in them, because these are used for purposes of identification and individually influence the different properties of the stone to a marked degree. The number of important or essential minerals in building stones are comparatively few, but in addition to these there are many of subordinate rank, often in such small grains as to be scarcely visible to the naked eye. Their presence may be of scientific interest, but the majority of them, except when present in large amount (and this is rare), exert but little influence on the character of the rock.

ROCK-FORMING MINERALS.[1]

A mineral may be defined as a natural inorganic substance of definite chemical composition occurring in nature.

There are a great many known mineral species, but only a very small number are important constituents of building stones. Not a few others are present in very small amounts, — scattered grains, — sometimes of microscopic size. These in many cases have little or no effect on the quality of the stone.

Physical Properties. In the determination of minerals, certain physical characters, such as the cleavage, hardness, lustre and crystal form, are commonly made use of, and in the study

[1] Those desiring to read up the subject of rock-forming minerals in more detail are referred to Dana, "Minerals and How to Study Them" (Wiley & Sons); also Hatch, "Mineralogy" (Whittaker and Co.).

of rocks, by means of thin sections examined under the microscope, the optical properties of the minerals are of great diagnostic importance.

The more important physical properties may now be defined.

Hardness. The different mineral species usually show a definite degree of hardness, and this property can be expressed numerically, with reference to a graded scale of 10 minerals, ranging from those which are very soft to the hardest ones known. This scale is as follows:

1. Talc.	6. Orthoclase.
2. Gypsum.	7. Quartz.
3. Calcite.	8. Topaz.
4. Fluorite.	9. Sapphire.
5. Apatite.	10. Diamond.

Any member of the series will scratch any of the others below it. Talc is readily scratched by the finger nail, and gypsum with difficulty. A good steel blade will barely scratch orthoclase, and quartz is sufficiently hard to scratch glass.

The hardness of any other mineral can be determined by testing it with those of the hardness scale. Thus if a mineral is scratched by quartz but not by orthoclase, its hardness is 6.

Cleavage. Many minerals possess the property of splitting more or less readily in certain directions. This is termed the cleavage. Some minerals exhibit but one system of cleavage planes, others two or three. These cleavage systems intersect each other at definite angles. In orthoclase feldspar, for example, the cleavage planes cause the mineral to break off with square corners. Cleavage planes may be parallel to crystal faces.

Lustre. Minerals often show a more or less characteristic lustre on either the crystal faces, cleavage planes, or fracture surfaces. These lustres may be designated as vitreous, pearly, resinous, dull, earthy, metallic, etc. Quartz shows a vitreous lustre, and gypsum a pearly one.

Form. If minerals have room to grow, they usually form crystals of definite outline, bounded by plane faces, but in most

rocks formed by the crystallization of minerals these are so crowded that they have no space to grow freely and complete their form. The grains are therefore termed crystalline.

Having described briefly the common physical properties, the more important minerals found in building stones may next be taken up.

Quartz. This mineral, which is composed of silica, is a very abundant one in many building stones. It is insoluble in all acids, except hydrofluoric, has a hardness of seven, no cleavage, a vitreous lustre, and a specific gravity of 2.6.

If pure it is transparent and colorless, but more often it is milky white, and small amounts of impurities may give it different colors. It is very resistant to the weather.

Flint and chert are amorphous or non-crystalline forms of silica, often of dark color, and form concretionary masses in certain rocks, especially limestones (Plate XXXI, Fig. 1).

Quartz is a common and important constituent of some igneous and metamorphic rocks and sandstones.

Feldspars. The feldspars are essentially silicates of alumina, with potash, soda or lime. Orthoclase and plagioclase are species of feldspar.

Orthoclase. This is a silicate of alumina and potash, but some of the latter may be replaced by soda. Its hardness is 6 and the specific gravity 2.54–2.56. It shows two sets of cleavage planes which intersect at right angles. Its lustre, on the cleavage planes, is somewhat glassy, and the color is commonly pink, sometimes very deep, less often whitish. Weathering destroys the lustre and, if carried to completion, converts the mineral into a white clayey mass.

It is a common constituent of granites and many gneisses, and may be present in sandstones.

Orthoclase is less durable than quartz, with which it is frequently associated, but is not to be regarded as unsafe on this account.

Plagioclase Feldspars. Under this head are grouped several feldspar species, which are silicates of alumina with soda or lime. They agree with orthoclase in hardness, but range from

2.62 to 2.75 in specific gravity. The plagioclases are usually white in color, and on certain cleavage planes show fine parallel lines. This, with their color, usually serves to distinguish them from orthoclase. They are less durable than the latter, but not sufficiently short-lived to cause the rejection of a stone containing them.

Plagioclase is a common constituent of some igneous rocks, such as diorite, diabase and gabbro, in which quartz is rare or absent.

Micas. Building stones, especially granites and gneisses, often contain two kinds of mica as prominent constituents. These are the white mica, or muscovite, and the black mica, or biotite. They are minerals of complex, as well as somewhat variable, chemical composition, but the former is essentially a silicate of alumina and potash, while the latter is a silicate of iron, alumina, magnesia and potash.

They occur in the rocks in the form of small shining scales, sometimes of six-sided character, with a very perfect cleavage, which causes them to split readily into thin elastic leaves.

Muscovite is silvery white in color, has a strong lustre, and is transparent in thin leaves. Its hardness is 2.–2.5.

Sericite is a very fine grained, silvery or light green type of muscovite, formed by the alteration of feldspar.

Biotite is black or dark green in color, when in thick plates or masses, but differs but little from muscovite in its lustre, although its hardness is slightly greater, i.e., 2.5–3.

Phlogopite, a nearly colorless mica resembling muscovite, is not uncommon in some crystalline limestones and serpentines.

Of the several kinds of mica, the muscovite is little affected by the weather, but the biotite, on account of its high iron content, is more liable to decompose on exposure to the weather.

The kind, quantity and distribution of mica in a building stone exerts an important influence on its durability and workability.

If present in abundance, and the scales are arranged in parallel layers, the rock may split readily along these planes. Such stones, especially sandstones, should be set on bed.

Mica, if abundant, is also an undesirable ingredient of marble used for exterior work, as it weathers out easily and leaves a pitted surface.

It is difficult to polish and therefore affects the continuity of the polished surface of a rock containing it.

Some building stones, such as granite, are rarely free from it, but in these it is not regarded as an injurious constituent unless present in large quantity.

The micas may, on account of their color, exert a strong effect in this direction.

Amphibole. This mineral, which is a complex silicate, has a number of varieties, of which hornblende is the most important in building stones. Tremolite is another.

Hornblende is a silicate of iron, lime, magnesia and alumina. It is dark green, brown or black in color, and occurs in compact, sometimes bladed, crystals of fair lustre. It resembles biotite but does not split into thin leaves as the latter does. Its hardness is 5–6. Unlike biotite mica, hornblende takes a polish and shows a better resistance to the weather than that mineral.

Hornblende is an important constituent of many igneous rocks and of some metamorphic gneisses and schists.

Tremolite (Plate XXXI, Fig. 2) is a pale-green variety of amphibole found in some crystalline limestones. It occurs in blade-like or silky-looking masses and is a detrimental mineral, since it tends to decompose to a greenish-yellow clay.

Pyroxene. This is a common mineral in some igneous rocks, especially the darker-colored or basic ones. Its composition and colors are similar to those of amphibole, from which it often cannot be distinguished with the naked eye when found in building stones. The dark-colored variety, augite, is an essential constituent of some igneous rocks, such as diabase and basalt, but may occur in other more acid ones.

Other varieties of pyroxene may be present in either igneous or metamorphic rocks but are not always visible to the naked eye.

Augite takes a good polish and shows fair durability.

Merrill states that the "pyroxene of the Quincy, Mass., granite proves to be an exceptionally brittle variety, and the continued

breaking away of little pieces during the process of dressing the stone makes the production of a perfectly smooth surface a matter of great difficulty."

Calcite. This mineral consists of carbonate of lime ($CaCO_3$). It is white, when pure, and has a hardness of 3; hence it is soft enough to be scratched with a knife. It effervesces readily when a drop of dilute acid is put on it.

Calcite is an important, and sometimes the only, constituent of many limestones, marbles and onyxes. Calcareous shales contain a variable quantity of it.

It may also occur as a secondary constituent of many igneous rocks, having been formed by the decomposition of other minerals, but in such cases it is usually present in but small amounts.

Sandstones may have some calcite as a cementing material. When exposed to the weather, calcite is dissolved by waters, especially those containing a little acid. The action is usually slow, but its effect is sometimes seen in limestone quarries where the rock has been dissolved out to a variable depth along the joint planes.

Aragonite, which has the same chemical composition as calcite but differs from it in crystalline form and specific gravity, occurs in some onyx marbles.

Dolomite. This mineral, which is a double carbonate of lime and magnesia, $(CaMg)CO_3$, is much like calcite, but differs from it in being slightly harder and in effervescing only with hot dilute acid. It is a common constituent of many limestones and marbles. Dolomite is less soluble in surface or rain waters than calcite but disintegrates more readily than the latter does.

Gypsum. This is a hydrous sulphate of lime ($CaSO_4 + 2\ H_2O$) and is not present in many building stones; indeed, it occurs only in stratified rocks. The mineral is soft enough to be scratched with the thumb nail, and its softness, together with the fact that it is not acted on by acids, serve to distinguish it from calcite.

Alabaster is a fine-grained, white variety, showing a translucency in thin plates.

Gypsum, though occurring in beds, is of little value for structural work.

Serpentine. Serpentine is a green or yellowish material, of soapy feel, without cleavage and soft enough to be easily cut with a knife. Chemically it is a hydrous silicate of magnesia ($Mg_3Si_2O_7 + 2\,H_2O$).

It is a common and important constituent of the serpentine or verd antique marbles used for decorative work, and in these occurs mixed with calcite or dolomite.

Its low resistance to the weather is mentioned later.

Talc or steatite is a hydrous magnesium silicate [$H_2Mg_3(SiO_3)_4$]. It is very soft, softer even than gypsum, and occurs commonly in the form of small greenish scales. It resembles mica, but the soapy feel, softness, and absence of elasticity in the scales serve to distinguish it from that mineral.

It is commonly an alteration product of minerals such as hornblende, augite, mica, etc. When it occurs in massive, somewhat impure form it is called *soapstone*, a material extensively used for sinks, washtubs, etc.

Olivine. This mineral, known also as chrysolite and peridot, is a silicate of iron and magnesia [$(MgFe)_2SiO_4$].

It has a hardness of 6–7, glassy lustre, and is often of bottle-green color, so that the rounded grains, if fresh, are easily recognizable in certain rocks, of which they sometimes form a characteristic ingredient. Olivine changes easily to serpentine.

Garnet. A silicate of alumina, lime, iron or magnesia, whose hardness is 6–7, color often red, and occurring in rounded grains. It is not uncommon in some rocks, such as mica schist, gneiss, granite or crystalline limestone.

The color and form cause garnets to be readily recognized.

Garnets are undesirable constituents of building stones, as, owing to their brittleness and hardness, they break away from the stone in the process of dressing and interfere with the production of a smooth surface.

Chlorite is a micaceous mineral or group of minerals which occur as secondary products in some igneous and metamorphic rocks and may impart a green color to them.

Pyrite or Iron Pyrite, an iron disulphide (FeS_2), is common in all kinds of rocks. Its yellow color and metallic lustre make it easily recognizable. When in grains large enough to be seen, it is found to form small cubes or irregular masses.

It is an undesirable constituent of building stones, especially ornamental ones, since it weathers somewhat easily to limonite, producing a rusty stain or causing disintegration of the rock.

Another form of iron sulphide, *marcasite*, decomposes even more readily.

Magnetite, or magnetic iron ore (Fe_3O_4), occurs as minute grains in many dark-colored igneous rocks (diabase, basalt, etc.), but is usually identifiable only on microscopic examination.

On exposure to the atmosphere it may change to the sesquioxide, causing a rusty stain on the rock.

Limonite, a hydrous oxide of iron ($2\ Fe_2O_3,\ 3\ H_2O$), is a common cement of many rocks, and is also formed by the decomposition of pyrite, and of iron-bearing silicates such as biotite, hornblende or garnet. It is of a yellowish-brown or brown color and non-crystalline character.

ROCKS.[1]

A rock may be defined as a natural aggregation of minerals forming a portion of the earth's crust.

According to their mode of origin, rocks can be divided into three great groups, the igneous, stratified and metamorphic.

The origin and essential characters of these may be briefly referred to.

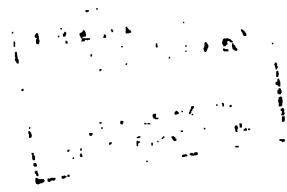
IGNEOUS ROCKS.

These have been formed by the cooling of a molten mass, or magma, which has come up from some variable and unknown depth in the earth's interior. As it cooled, the different minerals crystallized out to form a more or less tightly interlocking mass. The rock in some cases has solidified before reaching the surface, while in others it has flowed out on the surface as a lava stream.

[1] For more details than can be given here see Scott, "Introduction to Geology" (Macmillan Co.); Kemp, "Handbook of Rocks" (Van Nostrand); Pirsson, 'Rocks and Rock Minerals" (Wiley and Sons).

PLATE I. — A small fine-grained dike of dark diabase cutting a lighter-colored syenite. These dikes may be very narrow, or many feet in width.

PLATE II. — A volcanic rock, trachyte, showing porphyritic texture.



Those which cooled below ground are known as *plutonic* rocks and show varying forms, while those which have cooled on the surface are termed *volcanic* rocks.

Some masses of igneous rock are long and narrow (dikes), while others are irregular, or rudely dome-shaped in character (bathyliths and bosses).

With few exceptions, they agree in being of a massive structure, more or less crystalline in texture, and free from stratification planes. They differ in their texture, however, some being fine grained, others coarse grained.

Some are *even textured* (Plate III, Fig. 1), while others show a groundmass of small crystalline grains, embedded in which are larger ones, often of distinct crystal outline; this latter type of texture is termed *porphyritic* (Plate II).

In some cases lavas approaching the surface in the vent of a volcano are blown out with such force as to be disrupted into a mass of large and small fragments, which settle down on the surface. The coarser material is often called volcanic breccia, while the finer-grained deposit is termed tuff or ash. These ash deposits become subsequently cemented somewhat by the action of rain water.

In some countries, as Mexico, volcanic breccias and tuffs are extensively used for building purposes.

Igneous rocks are differentiated or classified on the basis of their mineralogical composition and texture.

The volcanic rocks may be glassy, cellular or porphyritic. The plutonic ones are usually massive and holocrystalline, porphyritic textures being rare, except in the dike rocks.

A rock might, therefore, preserve a uniform mineral composition, but vary in its texture, depending upon the conditions under which it cooled.

On the other hand, several plutonic rocks might agree in their texture, but differ in their mineralogical make-up.

These differences, either mineralogical or textural, lead to the development of different species.

The following table, taken from Pirsson, expresses simply the mineralogical and textural relationships of the more common types:

A. Grained, Constituent Grains Recognizable, Mostly Intrusive.

	a. Feldspathic rocks, usually light in color.		*b.* Ferromagnesian rocks, generally dark in color to black.	
	With quartz.	Without quartz.	With subordinate feldspar.	Without feldspar.
Non-porphyritic.	Granite.	Syenite. *a.* Syenite. Anorthosite.	Diorite. Gabbro. Dolerite. Diabase.	Peridotite. Pyroxenite.
Porphyritic.	Granite porphyry.	Syenite porphyry.	Diorite porphyry.	

B. Dense, Constituents Nearly or Wholly Unrecognizable. Intrusive and Extrusive.

	a. Light colored, usually feldspathic.	*b.* Dark colored to black, usually ferromagnesian.
Non-porphyritic.	Pelsite.	Basalt.
Porphyritic.	Pelsite porphyry.	Basalt porphyry.

C. Rocks Composed Wholly or in Part of Glass, Extrusive.

Non-porphyritic.	Obsidian, pitchstone, pumice.
Porphyritic.	Vitrophyre.

D. Fragmental Igneous Material. Extrusive.

Tuffs, Breccias (Volcanic ashes, etc.)

The above classification includes nearly all the more important rocks which are used for building purposes. There are many others but they are rarely used for structural or monumental work.

Those mentioned in the above table may now be briefly defined.

Granites (Plates III, IV). These consist essentially of quartz, orthoclase feldspar (sometimes microcline). Some species of mica, amphibole or pyroxene is usually present, and a number of others may occur as accessories, but they are usually of microscopic size. The texture is holocrystalline but varies from coarse to fine. Granites are sometimes classified according to some prominent accessory mineral, as muscovite, etc.

Pegmatite (Plate V) is a granite, usually of very coarse grain, and occurring commonly in the form of dikes. It is of no value

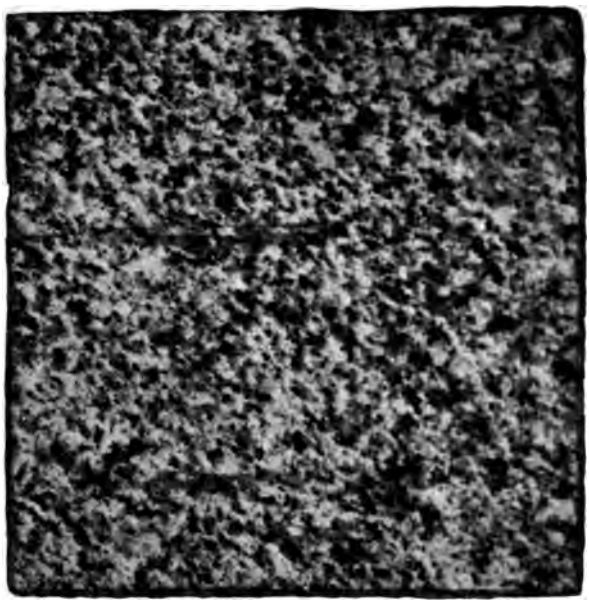


PLATE III, Fig. 1. — Moderately fine-grained granite, Hallowell, Me.

PLATE III, Fig. 2. — Very coarse-grained granite, St. Cloud, Minn.

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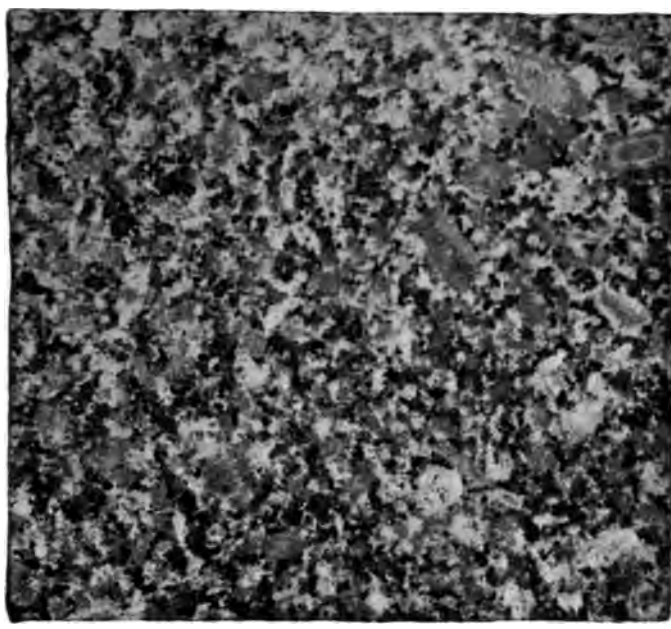

PLATE IV. — Coarse-grained, somewhat porphyritic granite from Crotch Island, Me.

as a building stone, but the occurrence of dikes of it in some quarries causes a serious waste.

Syenite. This is an even granular rock, composed chiefly of orthoclase feldspar and differing from granite only in the absence of quartz. Mica, hornblende or pyroxene are usually present. Syenites are sometimes porphyritic and grade into syenite porphyry. They may be white, pink or gray in color. They are not very abundant, and are of little importance as building stones.

Diorite. This is a granular intrusive rock composed of hornblende and feldspar, but often containing considerable biotite mica. The feldspar is a plagioclase.

Diorites are of a dark gray or greenish color, sometimes nearly black, while the grain varies from coarse to fine.

Intermediate forms between granite and diorite are known as *granite-diorite*. *Monzonite* is intermediate between syenite and diorite.

Gabbro. This is also a granular intrusive rock, which consists chiefly of pyroxene and feldspar. The latter may predominate to such an extent as to give the stone a very dark color. The color is dark gray or greenish to black. Magnetite in small black grains is often present, and so, too, may be olivine.

It is a common rock in the United States, being known in New England, the Adirondacks, in Maryland, Minnesota, the Rocky Mountains and California.

Though of value as a building stone, its dark color causes gabbro to be avoided.

Peridotite. A granular intrusive igneous rock composed of olivine and pyroxene without feldspar. It is mostly very dark in color.

Pyroxenite. This is also a granular plutonic rock, whose chief mineral is pyroxene, but which lacks olivine.

Granite Porphyry. A rock of porphyritic texture and same mineral composition as granite.

Syenite Porphyry. A porphyritic rock with phenocrysts of feldspar in a groundmass consisting chiefly of feldspar. The dark minerals biotite, hornblende or pyroxene may be present.

Diorite Porphyry. Consists of phenocrysts of hornblende and feldspar in a groundmass of the same minerals.

Felsite. This is a general term which includes fine-grained igneous rocks of stony texture and usually light color. They correspond to granites and syenites in mineralogical composition. In many cases the mineral grains are too small to be seen with the naked eye.

If of porphyritic character, and the phenocrysts are quartz, the rock may be called rhyolite, while if the phenocrysts are feldspar the name trachyte porphyry is used.

Felsites occur as dikes or more often as lava flows or sheets.

They are not uncommon in many parts of the United States.

Basalts. These correspond to the felsites in texture but are dark colored. Mineralogically they agree with gabbros or diorites. They are gray black to black in color, but their appearance is less lustrous than that of many felsites.

Basalt porphyry bears the same relation to basalt that felsite porphyry does to felsite.

STRATIFIED ROCKS.

This group includes a series of rocks of stratified character (Plate VI); that is to say, they are made up of layers.

They consist of material which has been derived from preexisting ones. To state their origin briefly it may be said that when rocks are attacked by the weathering agents they are broken down by physical and chemical processes.

Some of the products of decay, consisting of rock and mineral fragments, are washed down the slopes into the streams and carried by them to the lakes or sea, on the floor of which the material settles down as sediment. Additional quantities may be supplied by waves beating against the rocks exposed along the shore. Other portions of the rock masses referred to above are carried off in solution and reprecipitated, perhaps as chemical sediments, on the ocean floor or sometimes on the land, as in caves, ponds or around the mouths of springs.[1]

[1] There are other methods of accumulation but these are the most important.

PLATE V. — Pegmatite, showing coarse-grained texture.

PLATE VI, FIG. 1. — View in a limestone quarry, showing the horizontal stratification planes and vertical joint planes. (H. Ries, photo.)

PLATE VI, FIG. 2. — General view of a limestone quarry, showing stratified character of the rock.

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The accumulation of shell fragments on the ocean bottom may also cause deposits of considerable size and extent.

These ocean sediments may collect in considerable thickness and become consolidated (hardened), in part by pressure of many feet of overlying beds, and in part by the deposition of mineral matter around the grains, which serves as a cement to bind them together.

Later, by the uplift of the ocean bottom, such rock masses become elevated to form land.

Some stratified rocks, however, as sand, gravel and clay, may still remain soft.

The more important types may be defined.

Sandstone. This is a rock of varying hardness, whose grains are chiefly quartz. These grains are of varying size and are bound together usually by silica or iron oxide, although lime carbonate and even clay may also perform this function.

A micaceous sandstone is one containing mica scales. *Argillaceous sandstone* is a fine-grained phase containing considerable clay. *Arkose* is a variety containing much feldspar.

Conglomerate. This might be defined as a cemented gravel, the pebbles of which are more or less rounded, and may be of different kinds of rock. Conglomerates vary in their coarseness, and all gradations from a coarse quartz conglomerate to a sandstone may be found.

Shale. This is a thinly layered clay rock formed by the consolidation of clay. It is of no value as a building stone.

Limestone. A rock consisting, when pure, of lime carbonate or calcite and showing varying degrees of purity, hardness and texture. Sand and clay are common impurities and by an increase in these the rock may pass into sandstone and shale. Some varieties contain large quantities of shells and other fossils, which may stand out prominently on the weathered surface. Limestones vary in their color but white, gray or black are common ones. They are usually fine-grained. A drop of acid causes violent effervescence.

Of the varieties of limestones, the following are worth mentioning in this connection:

Chalk, a very soft limestone of earthy texture and usually white in color.

Calcareous tufa, a porous mass of lime carbonate, deposited around the mouth of springs, as in swamps. It often coats the plants growing in that locality.

Travertine is formed in a similar way but is more massive.

Onyx, a dense, crystalline form of lime carbonate, deposited usually on the floor of caves by percolating water carrying lime.

Coquina. A loosely cemented shell aggregate like that found near St. Augustine, Fla.

Dolomite. A rock composed of the carbonate of lime and magnesia. It resembles limestone in its hardness and color but often presents a more sandy appearance on the weathered surface. Effervescence is produced only with warm acid.

There is no sharp line of division between limestone and dolomite, the two grading into each other.

METAMORPHIC ROCKS.

Both igneous and stratified rocks sometimes become deeply buried in the earth's crust, in which position they may be subjected to great pressure or heat, or sometimes both. Without going into the causes of this, it may be simply stated that as a result of these two forces acting on the kinds of rocks above mentioned, they are often profoundly changed in their structure, texture, density and even mineral composition.

Metamorphic rocks usually show a crystalline or grained structure; they are dense and sometimes banded. Certain ones, like slate, split very regularly or with a perfect cleavage. Some rocks may be locally metamorphosed by intrusions of igneous rock.

The following are important types of metamorphic rocks:

Quartzite. A hard siliceous rock derived from sandstone and differing from the latter in being harder and denser.

Slate. A clay rock produced by the metamorphism of shale. In the process of change, the original stratification planes often become closed up, their position being indicated by the so-called *ribbons* in the slate. A new plane of splitting, known as the

cleavage, is developed, and it is the regularity and perfection of this which makes the slate of value for roofing purposes. By further metamorphism a slate may pass into a *schist*. (See below.)

The usual color of slate is dark gray or bluish black, but red, green and purple ones are also known.

Phyllite is a slate in a more advanced stage of metamorphism, and one in which the mica scales are not only more abundant but also visible to the naked eye.

Marble is a metamorphosed limestone. It is of crystalline or grained texture and may be either dolomitic or not. Clayey impurities that were present in the original rock have often been transformed into silicate minerals such as mica, these new minerals being frequently arranged in lines or belts, thus giving the rock a banded structure. Such marbles are far less resistant to the weather. Carbonaceous matter may cause gray coloration, sometimes of a streaky or banded character.

Marbles are affected by acid in the same manner as their unmetamorphosed equivalents.

Ophicalcite is a crystalline limestone with grains or patches of serpentine.

Gneiss (Plate VII). This is a banded or laminated metamorphic rock, which corresponds in its mineralogical composition to granite or some other plutonic rock. Thus we might have a *granilic gneiss*, a *syenilic gneiss*, etc.

Schist. This is more thinly foliated than gneiss, due usually to an excess of bladed or scaly mineral grains such as mica. The different varieties are named after some prominent component mineral such as *mica schist*, *hornblende schist*, *quartz schist*, etc.

Owing to their thin and irregular foliations, schists are of little value as building stones.

Schists may grade into gneisses on the one hand and into slates on the other.

STRUCTURAL FEATURES AFFECTING QUARRYING.

Two important structural features, which affect quarrying operations and also the market value of the stone, are *bedding* and *joints*.

Bedding (Plate VI). This refers to the separation of the rock into layers and is found in all stratified rocks. In some areas the rocks are in an undisturbed position and the layers are horizontal, while in other portions of the earth's crust the rocks have been disturbed by folding since their formation and the beds show varying degrees of tilt or dip.

The position of the beds is of importance. If they lie nearly horizontal, quarrying is begun in the upper layer, and only one bed can be quarried at a time. Moreover, if the good beds are covered by worthless ones, these latter must be first removed.

When a quarry is opened in a hillside, or where the beds are steeply upturned, the material in the different layers can be quarried at the same time, and thus one quarry is capable of producing several kinds of stone.

The marbles of Vermont are a good example of this, for there can be produced, at the same time from the various beds, marbles of pure white, cloudy, light water blue and dark bluish and greenish tints.

The bedding planes vary in their spacing in different quarries. In some they are widely separated, and consequently the rock is very massive and more expensive to quarry, although blocks of considerable thickness can be obtained.

In others the layers are very thin, and few stones of value are obtainable, but these thinly bedded rocks, if of sandy nature, are sometimes of value for flagging.

Stratified rocks split somewhat readily along their bedding planes.

Joints (Plates VI and XX). These are present in all kinds of rocks and represent fissures of varying length produced by several causes, such as shrinkage, twisting, crushing, etc.

Joints may traverse the rocks in different directions, and those which are parallel are regarded as belonging to the same series. There may be one or more series of vertical joints and a set of horizontal ones, these combining to break the rock into blocks of rectangular or cubical character.

Joints are an advantage in that they facilitate the extraction of the stone. They are a disadvantage if they serve as a path-

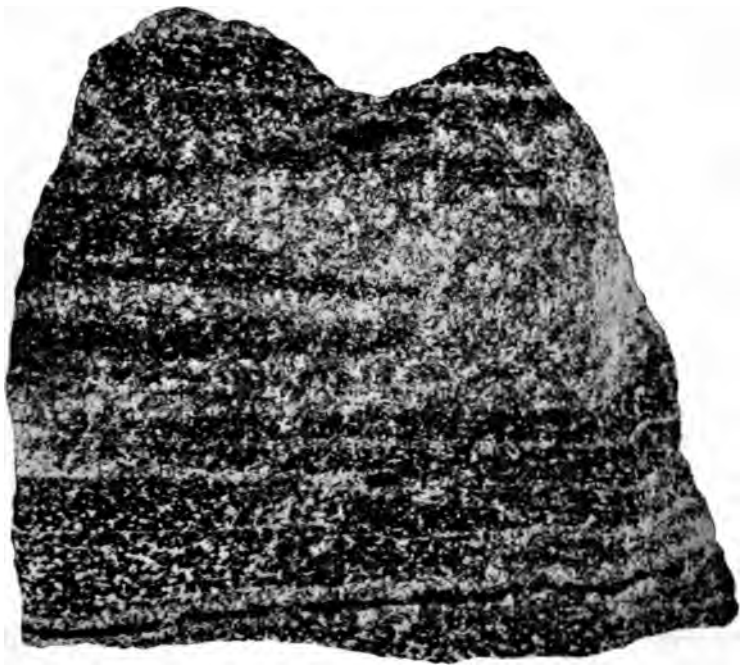

PLATE VII. — Biotite gneiss, showing characteristic banded structure of this rock.

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way for surface waters and weathering agents to enter the rock, and, moreover, they limit the size of the blocks that can be extracted from the quarry.

In some cases an otherwise good stone may be so cut up by joints as to be rendered worthless for any purpose except road material.

CHAPTER II.

PROPERTIES OF BUILDING STONE.

THE properties which have an important bearing on the value or durability of a stone, or on both, are: Texture, hardness, color, density, absorption, strength, resistance to frost, fire, abrasion or acid vapors, and chemical composition.

Many of these exert a direct or an indirect influence on the durability or life of a building stone, which will be referred to in more detail later.

The properties enumerated above may next be taken up in some detail, as they are nearly all of importance.

Texture. By texture is meant the grain of the stone. This may vary from coarse to fine or from regular to irregular. Most limestones are fine-grained. Sandstones, though commonly fine-grained, may show a coarse texture if representing transitional phases to a conglomerate.

Marbles vary from the finest textured forms, like those of Carrara, Italy, and Alabama, to others so coarse as to be undesirable for structural work. Similar variations exist in igneous rocks. Many of the latter may also show a porphyritic texture.

Fine-grained rocks, whose grains are closely fitting, are denser and may also be more durable. This is especially true in granites, the finer-textured ones being of longer life than the coarse-grained and the porphyritic ones.

If the mineral particles are not only large but of unequal hardness, the softer ones disintegrate more readily, thus leaving small pits on the surface. Cleavage cracks may also open up more easily in the large than in the small mineral grains.

Hardness. The hardness of a rock and the hardness of its component minerals should not be confused. The former depends on several factors, such as hardness of component minerals and relative abundance and state of aggregation. A

rock may therefore consist entirely of hard quartz grains and yet be bound together by so little cement that it will crumble under very little pressure. Another one similarly composed of quartz grains may be so well cemented by silica as to show a high crushing strength.

Hawes[1] has shown that the hardness of certain granites, for example, is not due entirely to quartz, which is hard and brittle and crushes under the tools, but that it is due to the feldspar, which is of variable hardness and has different cleavages.

Although hardness is an important quality there is no standard method of testing it, but the following ones are sometimes used.

Rosiwal, adopting Toula's principle,[2] uses a piece of smooth but unpolished granite of about 2 grams' weight and rubs it with emery (of 0.2 mm. diameter grain) upon a glass or metal plate for from 6 to 8 minutes until the emery loses its effectiveness. The granite is then weighed and its loss of volume calculated. Such a test is rather inaccurate.

A test suggested by J. F. Williams[3] consisted in noting the rate of penetration of a drill of a given diameter, or by measuring the distance to which such a drill will penetrate without being sharpened; or it might be possible to determine the amount of rough-pointed surface that could be reduced to bush-hammered surface in an hour. To make this last test of value a pneumatic drill or surfacer should be used.

Color. Building stones may show a variety of colors, including white, brown, red, yellow, gray, buff, black, etc. These colors, in many cases, are really of a composite character, being produced by a blending of the colors of the individual minerals. Uniformity of color may be produced by uniformity of distribution of the mineral grains or by the rock being composed entirely of one mineral.

Among the igneous rocks, of which granite is the most commonly used for building purposes, a variety of colors is observable. Reds and grays, both common colors in granite,

[1] Tenth Census, X, pp. 16–18, 1888.

[2] Verhandl. K. k. geol. Reichsanstalt, 1896, p. 488, and quoted by Dale.

[3] Ann. Rep. Ark. Geol. Surv., I, 1890, p. 41.

are dependent on the proportion of red and white feldspar. A granite of white feldspar and quartz and muscovite mica is very light in color, especially if dressed with a smooth surface. Gray and dark gray granites often owe their color to an excess or appreciable quantity of dark minerals, such as pyroxene, hornblende and biotite.

Some igneous rocks with labrador feldspar have a distinctly iridescent color. The volcanic rocks may be either light or dark colored, depending on their mineral composition, some being even black. Some diorites, gabbros and diabases not uncommonly show a dull greenish-gray color.

Among the sedimentary rocks the different shades of brown, red, buff and yellow are due mainly to the occurrence of iron oxide. Gray, blue and black are commonly produced by carbonaceous matter. The white color of sandstones indicates the presence of clean quartz grains, while the same color in limestone is due to the predominance of calcite or dolomite.

In the metamorphic rocks the colors of marbles and quartzites are due to the same causes as in limestones and sandstones. Gneisses owe their color to that of the individual grains.

Variation in Color. Sedimentary rocks occasionally show a variation in color, not only in the same quarry but even within short distances in the same bed. This is commonly due to irregularity of distribution of the coloring material, which may be disposed in regular bands or irregular spots.

In granites variations in color may be due to an increase or a decrease in the proportion of certain minerals in different parts of the quarry. Some granites show dark and unsightly spots, caused by the segregation of the darker minerals.

Change of Color. This may occur after the stone has been quarried. In stones colored black or gray by carbonaceous matter a slight fading is sometines noticeable. Some bright pink granites have also been known to fade on continued exposure to the sunlight. Certain sandstones, though white or light gray when freshly quarried, may, on exposure, change to buff or brown, owing to changes within the rock. These changes do not necessarily represent a weakening of the stone.

The Berea sandstone of Ohio changes to a buff color after a few years' exposure, due to the alteration of finely divided pyrite to limonite. In such cases no harm results, but if the iron sulphide (pyrite) is in large grains or lumps the limonite resulting from it may be carried in streaks over the surface of the stone, greatly marring its appearance.[1]

A whitish discoloration seen on the surface of some stones is an efflorescence derived from soluble salts. contained within the pores of the rock. It is brought to the surface by evaporation of water contained in the pores of the stone. In some instances it is traceable to the mortar.

Dust from the atmosphere will speedily discolor many light stones, and hence the use of white marble for exterior work is to be avoided in many cities where soft coal is extensively used. Architects, however, often show a cheerful disregard for such precautions. Such dirt will naturally adhere more strongly to a rough than to a smooth surface.

Some green slates are liable to change color on exposure to the atmosphere, but this does not necessarily indicate loss of strength.

The permanence of color of a stone can oftentimes be gauged by a comparison of the fresh face and weathered outcrop at the quarry.

An important property is the contrast which a stone shows between hammered and polished surfaces. It has to be considered if the stone is to be used for monumental or inscriptional work, and is most pronounced in those stones containing a greater abundance of transparent feldspar and darker minerals.

Remarkable as it may seem, fashion is a potent factor in the selection of building stones. Some years ago brownstone was used in unlimited quantities, and the monotonous rows of brownstone houses to be seen in many eastern cities attest the craze for this material. Incidentally, it was a costly one, for

[1] Streaking of a stone is sometimes caused by the mortar colors becoming washed out of the mortar joints. A custom, thoughtlessly pursued by some architects, is to fasten ironwork into the surface of a light stone, with the result that the rust from the iron invariably produces unsightly streaks

dozens of these buildings show the stone to be disintegrating, because it was placed on edge instead of on bed. Now the Berea sandstone and Bedford limestones are most used. One asks, What next?

Polish. The ability of a stone to take a polish depends on its density and the character of the mineral constituents. An aggregation of the same minerals, or even different minerals of the same hardness, permits of the development of a better polish than a mixture of minerals of varying hardness. Quartz, feldspar and calcite take a good polish, while hornblende and augite are less favorable. Micas are difficult to polish.

Specific Gravity and Porosity. The specific gravity of a stone is the weight of the stone compared with that of an equal volume of water. In order to determine it the stone should be first weighed dry; it should then be saturated as nearly as possible by boiling in distilled water, and weighed suspended in water. The specific gravity then is

$$G = \frac{D}{D - S},$$

in which

G = specific gravity

D = dry weight,

S = suspended weight.

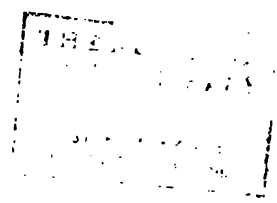
The average specific gravity of a number of stones is given by Hermann as follows:

Granite	2.65	Basalt	2.9
Quartz porphyry	2.6	Lava	2.15
Syenite	2.8	Gneiss	2.65
Diabase	2.8	Clay slate	2.7
Diorite	2.8	Limestone	2.6
Gabbro	2.95	Dolomite	2.8
Serpentine	2.6	Gypsum	2.3
Trachyte and andesite	2.7	Sandstone	2.1

The weight of the dry stone per cubic foot is obtained by multiplying its specific gravity by the weight of a cubic foot of water (62.8 pounds), but Buckley suggests there should be deducted from this the weight of a quantity of stone of the same specific gravity equal in volume to the percentage of the pore space of the stone.

PLATE VIII, Fig. 1. — Gray marble, Gouverneur, N. Y., showing contrast between tooled and polished surface.

PLATE VIII, Fig. 2. — Gabbro from Keeseville, N. Y., showing contrast between tooled and polished surface.



The porosity is obtained by the formula

$$P = 100\left(\frac{W - D}{W - S}\right),$$

in which

P = per cent porosity,
W = saturated weight,
D = dry weight,
S = suspended weight of saturated stone.

Foerster[1] gives the following porosity determinations as made by Hauenschild and Lang.

POROSITY PERCENTAGE OF DIFFERENT STONES.

Granite	0.04–0.61	Serpentine	0.56
Syenite	1.38	Sandstones:	
Diorite	0.25	von Salling	6.9
Porphyry	0.29–2.75	Nebraer	25.5
Basalt	1.28	Keuper	16.94
Diabase breccia	0.18	Carrara marble	0.22
Trachyte tuff	25.07	Tufa	32.2
		Roofing slates	0.045–0.115

Buckley's work on Wisconsin Building Stones[2] gives the following range of porosity:

Granites	0.019– 0.62
Limestones	0.55 –13.36
Sandstones	4.81 –28.28

Determinations made by the same writer on Missouri stones[3] gave:

Granites	0.255– 1.452
Limestone	0.32 –13.38
Sandstone	7.01 –23.77

It is contended by some that it is of more importance to determine the porosity than the absorption since the latter does not show the amount of water the stone is capable of holding and because there is no fixed ratio between pore space and absorption; moreover that the porosity together with the size of the

[1] Baumaterialienkunde, I, p. 13.
[2] Wis. Geol. & Nat. Hist. Surv. Bull. IV, p. 400, 1898.
[3] Mo. Bur. Geol. & Mines, II, 2nd Series, p. 317, 1904.

pores gives us a better index of the frost-resisting qualities. Stones of high porosity, but small pores are presumably less resistant to frost than those of high porosity and large pores.

It must be admitted, however, that in general a stone of high porosity shows high absorption, and that the determination of the latter gives us a rough index of the porosity.

Absorption. By this term is meant the amount of water which a stone will absorb when immersed in this liquid, and it should not be confused with porosity or the volume of pore space.

While stones with low porosity can absorb little water, and others with high porosity may absorb considerable water, nevertheless the absorption does not necessarily stand in any direct relation to the volume of pore space.

A high absorption is considered undesirable, as the freezing of the water in the pores of the stone may cause it to disintegrate, but this injury is often more pronounced in fine-grained than in coarse-grained materials, for the reason that in the former the water can drain off less readily.

Dense rocks, like granites, gneisses, slates, marbles, many limestones and quartzites, usually show a very low absorption, often under 1 per cent. Other rocks including many sandstones, some limestones (especially soft ones) and volcanic rocks like tuffs, may absorb from perhaps 2 up to 15 per cent of water.

Quarry Water. Many rocks, especially those of the sedimentary class, contain water in their pores when first quarried. This is known as quarry water, and may be present in some stratified rocks, such as sandstones, in sufficient quantities to interfere with the quarrying of them during freezing weather. The quarry water usually contains mineral matter in solution, and when the liquid evaporates, as the stone dries out, the former is left deposited between the grains, often in sufficient quantities to perceptibly harden the rock.

Crushing Strength. This is a property to which undue importance has probably been attached; indeed in some cases it may be the only test that is made on a stone. It can be safely assumed, as one writer has said, that a stone which "is so weak

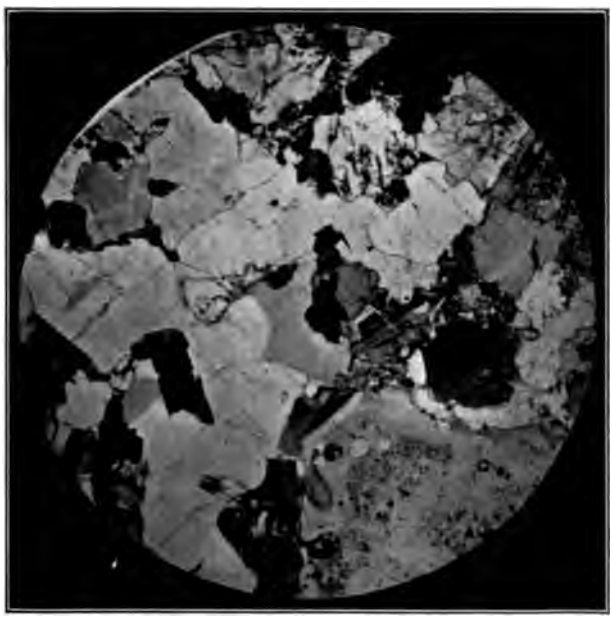
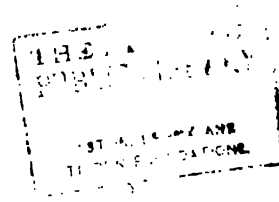


PLATE IX, Fig. 1. — Photomicrograph of a section of granite. (Photo by A. B. Cushman, from Ries's "Economic Geology.")

PLATE IX, Fig. 2. — Photomicrograph of a section of diabase. (Photo by A. B. Cushman, from Ries's "Economic Geology.")



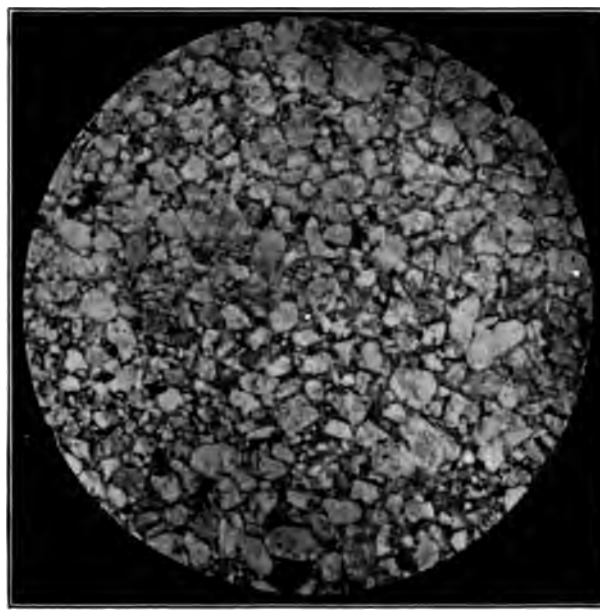


PLATE X. — Photomicrograph of a section of quartzitic sandstone. (From Ries's "Economic Geology.")

ASTOR, LENOX AND
TILDEN FOUNDATIONS

as to be likely to crush in the walls of a building, or even in a window stool, cap or pillar, bears such visible marks of its unfitness as to deceive no one with more than an extremely rudimentary knowledge on the subject." Few stones will, when tested, show a strength of under 6000 pounds per square inch, and many, especially igneous ones, stand as high, 20,000 to 30,000 pounds per square inch.

To be sure, in some large buildings a single column or block may be called upon to carry a heavy load, but even then it probably does not approach the limit of strength of the stone.

Merrill has shown that the stone at the base of the Washington monument supports a maximum pressure of 22.658 tons per square foot, or 314.6 pounds per square inch.

Allowing a factor of safety of twenty would only require the stone at the base of the monument to sustain 6292 pounds per square inch. Even at the base of the tallest buildings the pressure is probably not more than 160 pounds per square inch.

The crushing strength of a stone is commonly obtained by breaking a cube (usually 2-inch) in a special testing machine. Great care should be taken to see that the cubes are prepared with the sides smooth and exactly parallel. In some cases, instead of preparing the surface of the cube carefully, it is only made approximately smooth and bedded between the plates of the machine with pasteboard or plaster of Paris.

Unfortunately there is no standard size of cube used for testing purposes, and this may lead to variable results since the crushing strength per square inch does not appear to vary directly as the size of the cube.

All cubes should be thoroughly dried before testing.

The crushing strength of a stone is dependent on the state of aggregation of the mineral particles. In sedimentary rocks it depends on the character and amount of cementing material (Plate X), while in igneous and metamorphic rocks it is dependent on the interlocking of the mineral grains (Plate IX). This interknitting of the minerals produces a higher crushing strength in the two last-named classes of rocks.

Many crushing tests have been published, but it is not always safe to compare them, because the conditions of testing have not been uniform.

Wet stones show a lower crushing strength than dry ones, and exposure to repeated freezings may also lower the resistance to crushing.

The following tests made by Buckley on Wisconsin stones show this to be true in some cases:

CRUSHING STRENGTH OF WISCONSIN STONES BEFORE AND AFTER FREEZING.

Kind of rock.	Location.	Crushing strength, fresh.	Crushing strength, frozen.
Granite	Athelstane	19,988	10,619
...do	Berlin	24,800	36,009
...do	...do	45,841	32,766
...do	Montello	38,244	35,045
Limestone	Duck Creek	24,522	28,392
....do	Sturgeon Bay	35,970	20,777
....do	Wauwatosa	18,477	25,770
....do	Burlington	12,827	7,554
Sandstone	Presque Isle	5,495	5,930
....do	Dunnville	2,722	3,464
....do	Port Wing	5,329	4,399

Additional figures are given by Watson for North Carolina sandstone.

CRUSHING TESTS OF NORTH CAROLINA SANDSTONE.

Per cent absorption.	Conditions.	Crushing strength, lbs. per sq. in.
4.2	Dry	10,322
		11,150
	Wet	6,962
		5,837
	Frozen	6,625
		6,875
3.71	Dry	12,250
		11,232
	Wet	5,637
		6,712
	Frozen	6,287
		6,500

Tournaire and Michelot found that cubes of chalk 10 cm. in diameter showed a crushing strength, when wet, of 18.6 kilograms; when air dried, of 23.5 kilograms, and, when stove dried, of 86.2 kilograms.

Stones usually weaken when subjected to continued or intermittent pressure, and may break considerably below their normal ultimate crushing strength. However, great difficulty is experienced in obtaining satisfactory data on this point, for the reason that it is difficult to tell within a range of 1000 to 5000 pounds the crushing strength of samples to be tested (Buckley).

The following figures from tests by Buckley for Missouri and Wisconsin, and by Marston for Iowa, will give some idea of the variations which exist in the different groups of stones.

State.	Kind.	Range, lbs. per sq. in.
Missouri	Limestones	5,714–27,183 on bed.
....do	....do	5,774–25,577 on edge.
....do	Sandstone	4,371– 9,002 on bed.
....do	....do	3,933– 9,206 on edge.
....do	Granite	18,236–19,410 average.
Wisconsin	Igneous rocks	15,009–47,674
....do	Limestone	6,675–42,787 on bed.
....do	....do	7,508–40,453 on edge.
....do	Sandstone	4,340–13,069 on bed.
....do	....do	1,703–12,566 on edge.
Iowa	Limestones	2,470–16,435
..do	Sandstones	3,600–13,900

Transverse Strength. The transverse strength represents the force required to break a bar 1 inch square resting on supports 1 inch apart, the load being applied in the middle. This is measured in terms of the *modulus of rupture*, which is computed from the formula:

$$R = \frac{3}{2}\frac{wl}{bd^2},$$

in which

R = modulus of rupture,
w = weight required to break stone,
l = distance between supports,
b = width of stone,
d = thickness of stone.

The importance of this test has not been universally recognized, and it is therefore rarely carried out. Many a stone used for a window sill or cap has cracked under transverse strain (Fig. 1), because its modulus of rupture in the section used is too low. Such transverse breaks are not uncommonly caused by the settling of the building.

Fig. 1. — Sandstone broken by transverse strain caused by settling of the building.

It is of importance to note that the transverse strength does not appear to stand in any direct relation to the crushing strength.

In a series of samples tested from Wisconsin and Missouri by E. R. Buckley, the following variation was noticed:

MODULUS OF RUPTURE.

Kind.	Wisconsin.	Missouri.
Granite	2,324.3–3,909.7	.....
Limestone	1,164.3–4,659.2	851.30–3,311.60
Sandstone	362.9–1,324.0	418.61–1,321.76

Of some interest also is the following set of tests taken from the Report on Tests of Metals, etc., for 1895, issued by the War Department. These represent the relative transverse strength of stones in the natural state and after exposure to hot and cold water baths. It will be noticed that in every case this treatment resulted in a lowering of the transverse strength.

RELATIVE TRANSVERSE STRENGTH OF STONES IN NATURAL STATE AND AFTER EXPOSURE TO HOT AND COLD WATER BATHS.

Description.	Modulus of rupture per square inch.			
	Natural state, total.	After exposure to hot and cold water baths.		
		Total.	Loss.	Per cent of natural state.
	Pounds.	Pounds.	Pounds.	
GRANITES.				
From Braddock quarries, near Little Rock, Ark.	1,704	1,244	460	.....
From Millbridge, Me., " White Rock Mountain "	2,069	2,027	42	.....
From Rockville, Stearns County, Minn.	1,423	1,230	193	.....
Drakes granite, from Sioux Falls, Minn.	1,378	1,053	325	.....
From Branford, Conn.	1,415	1,083	332	.....
From Troy, N. H.	2,335	2,002	333	.....
Means.	1,721	1,440	281	83.7
MARBLES.				
Rutland White, Vt.	1,202	291[1]	911	.....
Mountain Dark, Vt.	2,109	1,408	701	.....
Sutherland Falls, Vt.	3,054	1,531	1,523	.....
From St. Joe, Ark.	1,615	567	1,048	.....
From DeKalb, St. Lawrence County, N. Y.	1,144	533	611	.....
From Kennesaw quarry, Tate, Ga.	1,553	605	948	.....
Means.	1,779	822	957	46.2
LIMESTONES.				
From Isle La Motte, Vt.	2,493	786	1,707	.....
From Mount Vernon, Ky.	1,434	1,076	358	.....
From Beaver, Carroll County, Ark.	2,860	2,247	613	.....
From Bowling Green, Ky.	1,317	799	518	.....
Blue colored from Bedford, Indiana.	1,867	958	909	.....
Means.	1,994	1,173	821	58.8
SANDSTONES.				
From Cromwell, Conn.	2,243	1,500	743	.....
From Worcester quarry, East Long Meadow, Mass.	987	1,189	202	.....
From Kibbe quarry, East Long Meadow, Mass.	1,273	655	618	.....
From Cabin Creek, Johnson County, Ark.	2,442	890	1,552	.....
Quarries near Fort Smith, Ark.	1,761	1,185	576	.....
From Olympia, Wash.	2,073	2,297	224	.....
From Chuckanut, Wash.	2,016	961	1,055	.....
From Tenino, Wash.	667	323	344	.....
Means.	1,683	1,125	558	66.9
Means of all stones.	.....	.....	.....	65.1

[1] Heated in hot-air oven to 402° F.

Frost Resistance. A stone for building purposes should resist the action of frost, and its disintegration by this agency is due to the water absorbed by it freezing within the pores of the rock.

When water freezes it expands, and if this water is imprisoned in the pores of the stone it may exert sufficient internal pressure to disrupt the same.

With other things equal, one might expect a stone of high absorption to disintegrate more easily than one of low absorption. This, however, is not always the case, for there are variable factors which affect the result.

Among these may be mentioned the size, shape and distribution of the pores, and rigidity of the rock.

A rock with large pore space may absorb a high percentage of water and yet not be affected, because the water either drains off rapidly or else is forced outward through the large pores.

On the other hand, a stone with small pores, or crooked ones, retains longer the water absorbed by it, and this on freezing often exerts sufficient internal pressure to split the stone.

The frost resistance of a building stone is an important property to determine, and laboratory tests should as far as possible simulate the conditions to which the stone is exposed when in use.

The most logical method consists in soaking the stone in water to fill the pores as thoroughly as possible, and then exposing it to a temperature below freezing. This should be repeated at least 20 times, and any loss in weight measured or any disintegration noted.

An artificial method consists in soaking the stone in a solution of sulphate of soda, and then drying it out, the theory being that the growth of the sulphate of soda crystals in the pores of the rock exerts internal pressure. The treatment is repeated a number of times.

This is much more severe than the ordinary freezing test, and gives abnormal losses by disintegration.[1]

[1] For further discussion of this subject see Merrill, "Stones for Building and Decoration," 3rd. ed., p. 463; Luquer, Trans. Am. Soc. Civ. Engr's, Mar., 1895, p. 235.

The effects of alternate freezing and thawing may be shown in several different ways, such as: (1) Formation of cracks, (2) detaching of grains from surface, and (3) loss of strength.

The second type of loss might occur in a laboratory test without being accompanied by any serious disintegration of the stone, as the surface of many dressed stones is coated with partly loosened grains.

Buckley, in a series of tests made on the Wisconsin stones, subjected to thirty-five alternate freezings (outdoors) and thawings, found the following losses in weight: Granites and rhyolites, not over 0.05 per cent. Limestones, not over 0.3 per cent. Sandstones, not over 0.62 per cent.

A set of Missouri building stones tested by the same author gave the following losses: Limestones, 0.006–0.909 per cent. Sandstones, 0.111 to 0.591.

Fig. 2. — Effect of fire on granite columns, U. S. Public Storehouse, Baltimore, Md.

Fire Resistance. It is well known that during the destruction of a building by fire, building stones often suffer serious disintegration. This may be due to unequal stresses set up within the stone by the exterior of a block becoming highly heated while the interior is still comparatively cool, or it may also be caused by the stone becoming first highly heated, and then being suddenly cooled by the application of a stream of cold water.

The last-mentioned combination of heat and cold seems in all cases to be productive of far more destructive effects than heating and subsequent slow cooling.

The best form of test to determine the fire resistance of a building stone consists of building up a section of masonry of the stone to be tested.

This may form the interior of a chamber which can be heated to redness, or be built up in an iron framework which forms one movable wall of a furnace.

In either case the stone after being heated to about 1750° F. is cooled down by a strong stream of cold water from a hose.

Many stones after heating to redness and slow cooling emit a dull sound when struck. Lime rocks, if heated above 850° C., calcine to quicklime, but at a lower temperature they are less affected by heating and slow cooling than any other rocks. Granites seem on the whole to have a lower resistance than sand-stones. Considered as a class, however, building stones are of low fire resistance, especially if rapidly cooled. In comparative tests they are often found inferior to clay products of non-vitrified character.

A most interesting series of tests was made some years ago by by W. E. McCourt,[1] for the New York and New Jersey Geological Surveys, on a series of three inch cubes.

The tests consisted in: 1. Heating two cubes to 550° C. and cooling one cube fast, the other one slow. 2. Similar treatment of two other cubes at 850° C. 3. Heating for five-minute intervals in a strong blast and cooling for alternate five minutes. 4. Alternately heating in a blast for five minutes and quenching with water for five minutes.

Professor McCourt in summarizing his New York tests made the following interesting statements:

"At 550° C. (1022° F.) most of the stones stood up very well. The temperature does not seem to have been high enough to cause much rupturing of the samples, either upon slow or fast cooling. The sandstones, limestones, marble and gneiss were slightly injured, while the granites seem to have suffered least.

[1] N. Y. State Museum, Bulletin 100, 1906; also N. J. Geol. Surv., Ann. Rept. for 1906, p. 17, 1907; see, further, Humphrey, U. S. Geol. Surv., Bull. 370, 1909.

PLATE XI. — Fire tests on 3 inch cubes of sandstones from Pleasantdale, N. J. (After W. E. McCourt.)

77. 550° C., slow cooling.
76. 850° C., slow cooling.
179. flame test.
78. 550° C., fast cooling.
75. 850° C., fast cooling.
148. flame and water test.

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PLATE XII. — Fire tests on 3 inch cubes of limestone, Newton, N. J. (After W. E. McCourt.)

216. 550° C., slow cooling.
217. 550° C., fast cooling.
218. 850° C., slow cooling.
219. 850° C., fast cooling.
220. flame test.
221. flame and water test.

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PLATE XIII. — Fire tests of 3 inch cubes of gneiss, Mt. Arlington, N. J. (After W. E. McCourt.)

228. 550° C., slow cooling.
229. 550° C., fast cooling.
230. 850° C., slow cooling.
231. 850° C., fast cooling.
232. flame test.
233. flame and water test.

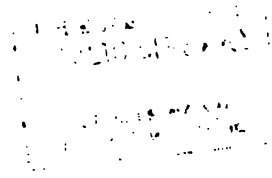


PLATE XIV. — Fire tests of 3 inch cubes of sandstone, Warsaw, N. Y.
(After W. E. McCourt.)

2. 550° C., slow cooling.
4. 850° C., slow cooling.
171. flame test.
1. 550° C., fast cooling.
3. 850° C., fast cooling.
139. flame and water test.

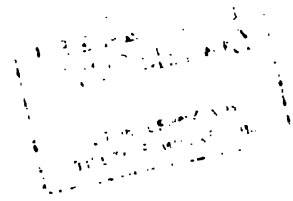
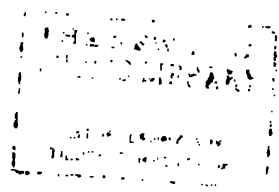


PLATE XV. — Fire tests of 3 inch cubes of diabase, Lambertville, N. J.
(After W. E. McCourt.)

255. 550° C., slow cooling.
256. 550° C., fast cooling.
257. 850° C., slow cooling.
258. 850° C., fast cooling.
259. flame test.
260. flame and water test.



"The temperature of a severe conflagration would probably be higher than 550° C., but there would be buildings outside of the direct action of the fire which might not be subjected to this degree of heat and in this zone the stones would suffer little injury. The sandstones might crack somewhat; but, as the cracking seems to be almost entirely along the bed, the stability of the structure would not be endangered, provided the stone had been properly set.

"The gneiss would fail badly, especially if it were coarse-grained and much banded. The coarse-grained granites might suffer to some extent. These, though cracked to a less extent than the sandstones, would suffer more damage and possibly disintegrate if the heat were long continued, because the irregular cracks, intensified by the crushing and shearing forces on the stone incident to its position in the structure, would tend to break it down. The limestones and marble would be little injured.

"The temperature of 850° C. (1562° F.) represents the probable degree of heat reached in a conflagration, though undoubtedly it exceeds that in some cases. At this temperature we find that the stones behave somewhat differently than at the lower temperature. All the cubes tested were injured to some degree, but among themselves they vary widely in the extent of the damage.

"All the igneous rocks and the gneiss at 850° C. suffered injury in varying degrees and in various ways. The coarse-grained granites were damaged the most by cracking very irregularly around the individual mineral constituents. Naturally, such cracking of the stone in a building might cause the walls to crumble. The cracking is due, possibly, to the coarseness of texture and the differences in the coefficients of expansion of the various mineral constituents. Some minerals expand more than others and the strains occasioned thereby will tend to rupture the stone more than if the mineral composition is simpler. This rupturing will be greater, too, if the rock be coarser in texture. For example, a granite containing much plagioclase would be more apt to break into pieces than one with little plagioclase for the reason that this mineral expands in one direction and contracts in another, and this would set up stresses of greater proportion than would be occasioned in a stone containing little of this mineral. . . . . In the gneisses the injury seems to be controlled by the same factors as in the granites, but there comes in here the added factor of banding. Those which are made up of many bands would be damaged more severely than those in which the banding is slight.

"All the sandstones which were tested are fine-grained and rather compact. All suffered some injury, though, in most cases, the cracking was along the lamination planes. In some cubes, however, transverse cracks were also developed.

"The variety of samples was not great enough to warrant any conclusive evidence toward a determination of the controlling factors. It would seem, however, that the more compact and hard the stone is the better will it resist extreme heat. The following relation of the percentage of absorption to the effect of the heat is interesting. In a general way the greater the absorption, the greater the effect of the heat. A very porous sandstone will be reduced to sand and a stone in which the cement is largely limonite or clay will suffer more than one held together by silica or lime carbonate.

"The limestones, up to the point where calcination begins (600°–800° C.), were little injured, but above that point they failed badly, owing to the crumbling caused by the flaking of the quicklime. The purer the stone, the more will it crumble. The marble behaves similarly to the limestone; but, because of the coarseness of the texture, also cracks considerably. As has been mentioned before, both the limestone and marble on sudden cooling seem to flake off less than on slow cooling.

"The flame tests can not be considered as indicative of the probable effect of a conflagration upon the general body of the stone in a building, but rather as an indication of the effect upon projecting cornices, lintels, pillars, carving and all thin edges of stonework. All the stones were damaged to some extent. The limestones were, as a whole, comparatively little injured, while the marble was badly damaged. The tendency seems to be for the stone to split off in shells around the point where the greatest heat strikes the stone. The temperature of the flame probably did not exceed 700° C., so it is safe to say that in a conflagration all carved stone and thin edges would suffer. However, outside of the intense heat, the limestones would act best, while the other stones would be affected in the order: sandstone, granite, gneiss and marble.

"After having been heated to 850° C., most of the stones, as observed by Buckley, emit a characteristic ring when struck with metal and when scratched emit a sound similar to that of a soft burned brick. It will be noted that in those stones in which iron is present in a ferrous condition the color was changed to a brownish tinge owing to the change of the iron to a ferric state. If the temperature does not exceed 550° C., all the stones will stand up very well, but at the temperature which is probable in

a conflagration, in a general way, the finer grained and more compact the stone and the simpler in mineralogic composition the better will it resist the effect of the extreme heat. The order, then, of the refractoriness of the New York stones which were tested might be placed as sandstone, fine-grained granite, limestone, coarse-grained granite, gneiss and marble."

Expansion and Contraction of Building Stones. Building stones expand when heated and contract when cooled, but do not return to their original length. This slight increase in size is known as the "*permanent swelling.*" The determination of this change in volume has a twofold value, as it permits the making of proper allowance for expansion in walls, and also because it may weaken the stone somewhat.

The following averages are based on experiments made at the Watertown arsenal,[1] the permanent swelling being for a bar 20 inches long, heated and cooled through a range of temperature from 32° F. to 212° F.

	Inch.
Granite	0.004
Marble	0.009
Limestone	0.007
Sandstone	0.0047

The accompanying table gives the coefficients of expansion of a number of stones as determined in a water bath:[2]

COEFFICIENTS OF EXPANSION OF STONES, AS DETERMINED IN WATER BATHS.

Name.	Location.	Original gaged length in air.	Temperature.				Coefficient of expansion.
			Hot.	Cold.	Difference.	Difference in length.	
		ins.	deg.	deg.	deg.	ins.	
Buff oölitic limestone	Bedford, Ind.	20.0033	178	33.5	144.5	0.0109	0.00000375
Limestone	Indiana	20.0084	177	33.5	143.5	0.0108	0.00000376
Marble	Vermont	19.9989	203	34	169	0.0122	0.00000361
Marble	Lee, Mass.	20.0061	189.5	33.5	156	0.0175	0.00000562
Red sandstone	Maryland	20.0034	183	33.5	149.5	0.0152	0.00000501
Red sandstone	Portland, Conn.	19.9912	180	33.5	146.5	0.0154	0.00000526
Sandstone	Ohio	20.0019	183	33.5	149.5	0.0186	0.00000622
Slate	Monson, Me.	19.9954	194	34	160	0.0158	0.00000500
Bluestone	New York	20.0052	192	33.5	158.5	0.0189	0.00000596
Granite	Milford, Mass.	20.0023	183	33.5	149.5	0.0122	0.00000408
Granite	Quincy, Mass.	19.9951	199	33.5	165.5	0.0126	0.00000381
Granite	Rockport, Mass.	19.9303	181	33.5	147.5	0.0091	0.00000311

[1] Report on tests of metals, etc., at Watertown Arsenal, U.S. War Dept., 1895, pp. 322–23.

[2] Report on Tests of Metals, etc., U. S. War Dept., 1890.

Abrasive Resistance. The abrasive resistance of a stone depends in part on the state of aggregation of the mineral particles and in part on their individual hardness. Some stones wear very unevenly because of their irregularity of hardness, and such may be less desirable than those which are uniformly soft.

Merrill[1] states that a "serpentinous steatite" used many years ago for steps and sills in Philadelphia wore very unevenly, owing to the superior hardness of the serpentine over the steatite, causing the former in time to stand out like knots in decaying logs."

A test to determine the abrasive resistance should be made on those stones which are used for paving, steps, or flooring, in which position they are subjected to rubbing action. It is also of importance if the stone is placed in a situation where it will be subjected to the attacks of wind-blown sand or the rubbing action of running water carrying sand.

Several methods for determining the abrasive resistance of stone have been suggested, but none universally adopted.

A common method consists in laying the stone to be tested on a grinding table, weighting it down, and applying emery or some other abrasive at a given rate while the table revolves. The objections to this method are that one cannot be sure that the abrasive is being fed at a uniform rate or that all of it passes under the test piece.

Gary[2] endeavored to perfect the test by cutting slabs of 50 square centimeters' surface parallel with the bedding. These were held down with a 30-kilogram weight and placed about 22 centimeters from the center of the circular rubbing plate. At one-minute intervals, 20 grams of Naxos emery of a certain size were strewn on the table. The abrasive and abraded rock remained on the table until the completion of 110 revolutions, which consumed about five minutes. No water was used. The loss of weight of the stone indicated the amount of abrasion.

Another experimenter, Hannover, tried to improve on this method by using sandpaper, which held the abrasive grains in place.

[1] "Stones for Building and Decoration," p. 460.

[2] Baumaterialienkunde, II, p. 11, 1897–98.

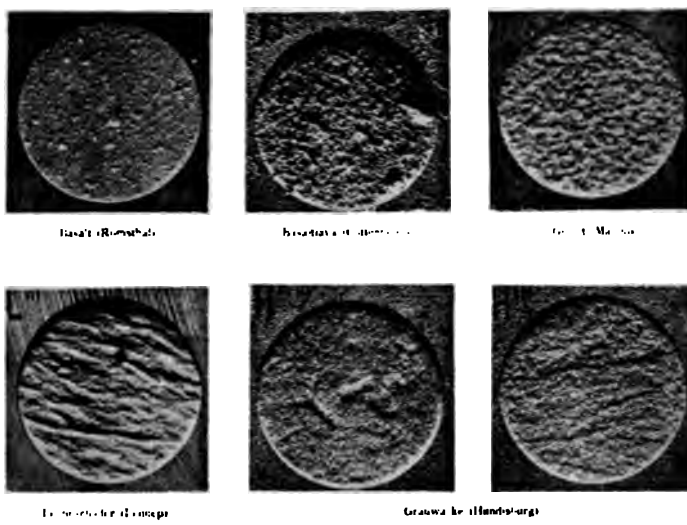


PLATE XVI. — Results of abrasion test with sand blast.
(After Gary, Baumaterialienkunde.)

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Owing to the difficulty of maintaining uniform conditions, the test is an unsatisfactory one and of use mainly where comparative results are desired and several pieces tested at the same time.

Gary[1] has also devised a sand-blast process which consists in forcing sand through a 6-centimeter diameter opening, under a dry-steam pressure of 3 atmospheres, for 2 minutes. The stone to be tested is held immediately over the opening Plate XVI.

The following figures give the results obtained by him with both methods:

ABRASION TESTS MADE BY GARY.

Name.	Abrasion on rubbing table.			Abrasion with sand blast.			
				Normal to bedding.		Parallel to bedding.	
	Surface.	Average loss.	Abrasion loss ratio of 1 c. cm.	Average loss.	Abrasive loss ratio of 1 c. cm.	Average loss.	Abrasive loss ratio of 1 c. cm.
	sq. cm.	c. cm.	sq. cm.	c. cm.	sq. cm.	c. cm.	sq. cm.
Basalt	50	5.4	0.11	1 70	0 06	1 81	0 06
Basalt lava	49	9 6	0.20	6 01	0 21	7 06	0 25
Granite	49	5 1	0.10	2 64	0 09	3 78	0 13
Gneiss	48	9.6	0 20	4 01	0 14	3 26	0 12
Porphyry	49	8.5	0.17	3 29	0 12	2 53	0 09
Graywacke	50	10.8	0.22	4 24	0 15	4 16	0.15
Sandstone	50	18.4	0.37	11 15	0 39	8 42	0.30
Schist	50	29.7	0.59	8 02	0 28	5 90	0.21

The sand-blast treatment not only tests the abrasive resistance but also brings out irregularities in the hardness.

Discoloration. Some building stones discolor on exposure to the atmosphere, the alteration involving a chemical change within the rock, caused by atmospheric action. The change in tone or color is usually slow.

In order to determine whether a stone contains any minerals likely to discolor the rock, a piece of fresh rock is immersed in a stream of carbon dioxide for 20 minutes and then placed in an atmosphere of that gas for 24 hours. A second piece is placed in pure oxygen over night and exposed for 30 minutes to a temperature of 150° C. Any discoloration caused by carbonization

[1] Baumaterialienkunde, X, p. 133, 1905.

or oxidation of any mineral in the rock is sure to become noticeable.

Another method consists in placing the stone to be tested on a glass shelf, in a covered glass jar containing hydrochloric acid. Alongside of the specimen are placed two open bottles, one containing hydrochloric acid and manganese dioxide; the other, strong nitric acid.

The chlorine and acid fumes rising and filling the chamber form an extremely corrosive and oxidizing mixture and quickly attack any oxidizable compounds where such exist.

The test piece is left in this atmosphere for several weeks and any change of color noted.

Effect of Sulphurous Acid Gas and Dilute Sulphuric Acid. The stones most affected by this treatment are limestones, which contain lime or magnesium carbonates. Sandstones with calcareous cement may also be attacked.

These acid gases mentioned above may be discharged into the atmosphere from chimneys or other sources and carried to the surface of the stone by moisture, or they may originate in the stone itself by the decomposition of pyrite or marcasite if these minerals are present.

While their action is slow it is nevertheless not to be overlooked.

The resistance of a rock to sulphurous acid gas is sometimes tested by placing carefully dried two-inch cubes in a sealed wide-mouthed bottle kept at a temperature of 110° C. Water in the jar keeps the air moist, and sulphur dioxide gas is fed into it in sufficient quantity to saturate the atmosphere. After 30 or 40 days' exposure to these conditions the samples are removed, washed, thoroughly dried and weighed, the loss of weight, if any, showing the degree to which the stone has been attacked by the gas.

Dolomites may swell and crumble, because of the change of magnesium carbonate to magnesium sulphate.

Such a test is more severe than a stone would be subjected to in actual use.

Effect of Carbonic Acid Gas. This is most effective when it attacks calcareous rocks. Others may be but little affected.

The test may be carried out by placing weighed specimens dried at 110° C. in a large bottle. In this there is also a small vessel of water to keep the atmosphere moist. Pass carbon dioxide gas into the bottle until it displaces all the air present. Cover the bottle, allow to stand for six weeks, taking care to replenish the carbon dioxide about twice a week. At the end of the period mentioned, remove the stone, wash with distilled water, dry and weigh. The loss in weight indicates the extent to which it has been attacked.

Another way of making the test is to suspend the stone in water through which carbon dioxide gas is allowed to bubble.

Chemical Composition of Building Stones. Much money is spent on the analysis of building stones, but the returns are slight. This is because few interpretations can be made from such an analysis, for it throws no light on most of the properties which have been discussed in the preceding pages.

It is true that an analysis may show the difference between a limestone and a dolomite, but a simple test will do this. It may indicate whether a sandstone is pure or impure, but this too can be told with fair accuracy on inspection. It might indicate pyrite in a rock, but if the former is present in injurious amounts, its occurrence can usually be detected with the naked eye or hand lens. So, on the whole, the chemical analysis is not of much value for commercial purposes so far as building stones are concerned.

WEATHERING AND DECAY OF BUILDING STONES.

Under this term are included the physical and chemical changes which a stone undergoes when exposed to the weather. Some building stones are but little affected under any climatic conditions and are, therefore, long lived, while others disintegrate most rapidly.

All stones are, therefore, not equally well adapted to any kind of conditions, and since architects sometimes fail to recognize this fact, many a fine and expensive structure at the present day presents a most unsightly appearance.

Nowhere are the mistakes of this sort so evident as in the severe climate of our northeastern states, for moisture combined with heat and cold have wrought much havoc. The cracked and scaling fronts of brownstones in many eastern cities stand as a monument to the poor selection and improper placing of building stones.

While exposure to the weather may bring about noticeable changes in a stone, still it may be pointed out that these do not invariably indicate a weakening of the rock. The Berea, Ohio, sandstone is a noticeable example of this. Here the finely divided pyrite is very evenly distributed through the stone, and its change to limonite on exposure to the weathering results only in a change of color without loss of strength.

In judging the durability of a building stone, climatic conditions should be considered. Thus, the excellent state of preservation in which we find the obelisks of Egypt or the marble monuments of Rome is not due to any inherent qualities of the stone, but to the mild climate in which they have stood.

The Egyptian obelisk brought to New York City and set up in Central Park showed such rapid disintegration that it became necessary to cover it with a protective coating.

Stones may be broken down by the weather in two ways. The first of these is by physical means and is known as disintegration; the second, by chemical processes, known as decomposition. Either of these alone may work the ruin of the stone, but they are more apt to work jointly, although the one or the other may predominate.

The two classes of processes will next be discussed in more detail.

DISINTEGRATION.

Temperature Changes, or Heat and Cold. Stones expand when heated and contract when cooled. They are, moreover, poor conductors of heat, so that one side of a stone might be highly heated while the other side is still cool. This alone would produce an uneven expansion, tending to crack the mass.

Since different minerals have a different rate of expansion it is easily understood that continually repeated heating and cooling

PLATE XVII, Fig. 1. — Weathering of red sandstone, Denver, Colo. (Photo by R. D. George.)

PLATE XVII, Fig. 2. — Weathered sandstone, second story, County Court House, Denver, Colo. (Photo by R. D. George.)

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may set up a working within the mass that would tend to eventually loosen it up.

Bartlett[1] has determined that the expansion of different stones, for each degree of Fahrenheit, is as follows:

	Inch.
Granite	0.000004825
Marble	0.000005668
Sandstone	0.000009532

Taking the case of granite, we find that for a change of 100° F. and 100 feet of granite it would amount to about one-twentieth of an inch.

Expansion caused by Freezing. If a stone is porous and the pores are filled with water, far greater damage may result by changes of temperature, for the reason that water in freezing expands one-tenth. Now, if the pores are so filled with water which has no chance to escape, the internal pressure exerted by it will be very great, amounting to a little less than 150 tons per square foot, which a stone may not be able to resist.

Much misconception exists concerning the frost resistance of stones. If the pores are exceedingly small (sub-capillary), the water may have no chance to escape, while if large, the water drains off readily, and no damage results. Again, incomplete saturation of the rock leaves room for the water to expand in freezing without damaging the stone.

Two stones of equal porosity may differ in their frost resistance, and the one whose pores are quite minute will be more likely to suffer. Two stones having pores of equal size will vary in their resistance inversely as the amount of pore space.

As pointed out by Buckley, the amount of water which the pores contain at a given time depends (1) upon the amount of water initially absorbed, (2) the time that has elapsed since the water was absorbed, (3) the size of the pores, (4) the position of the stone, and (5) the condition of the atmosphere.

Much danger may also result from the accumulation of water in joint or bedding planes. This is especially pronounced if the stone is set on edge, for the water freezing in the parting planes pries off scales and chips at a rapid rate.

[1] Amer. Jour. Sci., XXII, 1832, p. 136.

Abrasive Action. Wind-blown sand is a common abrading agent in some regions, and in some cases, as those of tombstones in cemeteries, has removed the polish and even obliterated the lettering on monuments.

Stone which is used for sidewalks, flooring, stair-treads, etc., is especially exposed to the rubbing action of sand, ground against the surface by shuffling feet.

Much variation exists in this direction, some stones being but little affected, others becoming badly worn in a short time.

Plant Action. The action of plants is not altogether a physical one. On the outcrop, plant roots often penetrate the cracks and crevices of a stone and, as they grow and expand, exert sufficient pressure to pry off fragments, but this does not occur in buildings. There the rootlets of vines may penetrate the pores of an open rock, but they probably exert no physical force.

They may, however, aid in the decomposition of the rock by the formation of organic acids produced during decay. Moreover, they attract moisture to the stone.

Careless Methods of Extraction and Working. A stone may be weakened and rendered more vulnerable to the attacks of the weathering agents by improper methods of quarrying and working.

The use of heavy charges of powder or dynamite not only destroys a large quantity of stone, but also develops minute cracks — incipient joints — which permit the more ready entrance of water into the stone, with increased danger from freezing and thawing. The continuous striking of a stone with hammer and chisel in splitting or dressing it is likewise a possible cause of damage.

Injuries in quarrying may be avoided by taking advantage of the natural joints as much as possible, by the Knox system of quarrying, in which small charges of powder are properly distributed, or by the channeling system now much used in limestone, sandstone, marble and even slate quarrying.

Many stones should not be quarried in freezing weather, because the exposure may cause the quarry water in their pores to freeze.

The life of a stone depends to a limited extent on the method of dressing. The polished surface sheds water more easily than a rough one. A hammer-dressed rock, like sandstone, may disintegrate more rapidly than a sawed one.

Finally, position when in use is a matter not to be overlooked. Many stones of stratified or schistose character can be dressed more easily and more smoothly along the bed. On this account they are set in the wall on edge. This permits the rock to scale off more easily than if set on bed, for the pressure of the overlying blocks in the wall will resist the upward pressure of the freezing water, and it will exert itself parallel with the stratification.

Of course, some stones are so strongly knit together and the schistosity or stratification so slightly developed that they can be safely set on edge.

DECOMPOSITION.

The chemical processes working to break down the stone usually operate with slowness, although one at times finds marked exceptions. Important agents of decomposition are water, oxygen and acids. In most cases the changes wrought by these agents are so slow that they do not often affect the durability of the stone after it is set in the building; indeed, the limestones, dolomites and marbles are about the only ones in which decomposition advances at a sufficiently rapid rate to be noticeable.

Water may act by direct attack on the rock itself, or it may serve as a carrier of other injurious substances.

Pure water shows but little solvent action, but if contaminated by the presence of sulphuric, sulphurous, carbonic or organic acids its dissolving power is noticeably increased. Its work in this manner is most noticeable in limestones. Water in contact with these dissolves out small quantities here and there throughout the stone, and by thus removing more or less of its cement or even portions of the mineral grains themselves greatly weakens it. This effect is more pronounced in limestones than in dolomites. Sandstones having a calcareous cement may be similarly affected.

In rocks like granite the decomposition of minerals like feldspar, mica, or hornblende is a more complex process, involving more than simple solution. All of these minerals break down slowly to a more or less clayey mass, and if they contain iron, the latter is set free in the form of limonite (hydrous iron oxide), which develops a rusty stain. The changes in these silicates are usually so slow as to be almost negligible in building stones.

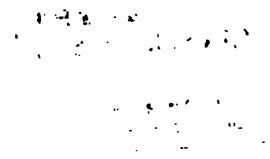
Where a rock like granite has, however, been exposed to the attacks of the weathering agents for many centuries, the upper portion of the mass may have become broken down to a plastic, often iron-stained clay. This residual clay forms a mantle overlying the parent rock and grades down into it. In the Southern Atlantic states, for example, where this overlying clay has not been removed by glacial erosion, as it has been in the Northern ones, it is sometimes necessary for the quarryman to strip off considerable material in order to reach sound rock. This will not be found at the same depths in all parts of the quarry, for where the vertical joints are more numerous the rotted rock is usually found to a greater depth.

The oxidation of pyrite often leads to troublesome results. This mineral, on exposure to moisture and air, changes to limonite, or rust.

If the sulphide is scattered through the stone in small grains no harm may result, as the change in color does not necessarily weaken the stone; on the contrary it may improve its looks. Furthermore, the deposition of this iron oxide around the grains may cement them more firmly together. In most rocks, however, the change in the pyrite leads to unsightly staining of the stone, and one containing any quantity of it in visible grains should be avoided. It may work further harm in limestones, because during its decomposition small quantities of sulphurous or sulphuric acids are formed which may attack some of the minerals of the stone.

Other iron compounds, like ferrous carbonate, or magnetite, may undergo an oxidizing action and, if abundant, give the rock a rusty tint.

PLATE XVIII. — Scum of soluble salts, which has caused surface disintegration of sandstone. (After Kaiser, Neues Jahrb. Min., 1907, II.)



Sulphurous and Sulphuric Acids. These may not only be produced by the weathering of pyrite as mentioned above, but may also be derived from the atmosphere, especially in those districts where acid fumes are discharged into the air from the stacks of factories, smelters, etc.

These acids attack the rocks, especially those containing carbonate compounds like limestones and dolomites and marbles. This results in these carbonates being converted into sulphates, a transformation involving change of volume. The sulphates thus formed may either lodge in the pores of the rock, or they may be brought to the surface by evaporating water and there form a scum.

An interesting case has been described by E. Kaiser,[1] of the disintegration by sulphates of the sandstone in the Cologne Cathedral (Plate XVIII):

> The weathered stones, which were certain ones used between 1842 and 1868, show externally an apparently unaltered scale, while between this and the solid stone within is a white layer of water-soluble salts. Sometimes there are several alternations of these layers. The cement of the fresh stone is a mixture of kaolin, barite and dolomite. No other sulphur mineral than barite is present in the stone. In the quarry the weathering consists in a solution of the calcium and magnesium components of the dolomite with deposition of the iron as hydrated ferric oxide. On the cathedral, however, the white layers are composed of sulphates of calcium and magnesium. The conclusion is inevitable that the sulphur is derived from the city smoke and that the process of disintegration can be halted only by the application of an impervious coating. Examination of structures in other parts of Germany, where the same stone has been used, shows a similar condition, the degree of attack varying with the relative production of smoke gases and the exposure of the structural material to these gases.

Carbon dioxide in solution may also exert a solvent action on calcareous rocks. Its effect on other kinds is scarcely noticeable in the building.

Organic acids, though playing an important rôle in the weathering of rocks in the field, exert but little influence on the stone in the wall.

Hardening of Stone on Exposure. All quarrymen are familiar with the fact that many stones harden on exposure to the atmosphere, this change being specially noticeable in limestones

[1] Neues Jahrb. Min. Geol. Pal., 1907, II, 42–64

and sandstones. So pronounced is this change that some stones are more easily dressed when freshly quarried than later.

The hardening has been considered by several investigators to be due to the fact that the water in the pores of the stone — the quarry water — contains a small quantity of dissolved mineral matter, which it deposits in the pores of the stone on evaporation. The formation of this additional cement, therefore, serves to bind the stone more tightly together. This cementing action, of course, takes place on or close to the surface, thus forming a protecting crust. On this account it is urged by some that the carving of a stone should be done before it dries out, thus permitting the crust to form on the carved surface.

The weathering qualities of the different classes of building stone will be more fully discussed under their respective heads.

Life of a Building Stone. This may be considered as the length of time a stone will stand exposure to the weather without showing signs of disintegration or decay. Even for the same stone it may vary with location, climate, and position in the wall.

The following table was compiled some years ago by Dr. A. A. Julien, from observations on building stones in New York City:

Kind of stone.	Life, in years.
Coarse brownstone	5 to 15
Fine laminated brownstone	20 to 50
Compact brownstone	100 to 200
Bluestone (sandstone), untried, perhaps centuries	
Ohio sandstone (best siliceous variety), perhaps from one to many centuries.	
Coarse fossiliferous limestone	20 to 40
Fine oölitic (French) limestone	30 to 40
Marble, coarse dolomitic	40
Marble, fine dolomitic	60 to 80
Marble, fine	50 to 100
Granite	75 to 200
Gneiss, 50 years to many centuries.	

There is no weight in the argument that Nature's processes are very slow, and that any building stone will last for several generations. This is not so. Any large city, where a variety of stones are used, will be apt to show cases of rapid decay if the climate is at all severe.

Merrill[1] cites the case of a coarse, gray Niagara limestone from Lockport, New York, used in the construction of the Lenox Library Building in New York City, which began to show signs of decay even before the structure was completed. But this extremely rapid rate was due in part to the fact that the stone was laid on edge.

A case which came under the writer's observation was that of the polished cipolino marble columns on the front of St. Bartholomew's Church at 44th Street and Madison Avenue, New York City. These in three years had lost their polish and were pitted and flaked to such a degree that it became necessary to rerub the surface and treat it with a preservative. This type of stone should never have been used for exterior work in the New York climate.

Pages might be filled quoting examples of this sort.

Sap. This is a rusty discoloration produced by iron, which is often found in those portions of the stone bordering joint planes. It is noticed especially in granites. In some cases it is due to the decomposition of iron-bearing minerals in the rock by surface waters; in others it may be an iron stain from water which filters downward along the joint planes.

LITERATURE ON BUILDING STONES.

As the architect or engineer is frequently desirous of knowing what the important printed sources of information on building stones are, it may be well to indicate some of the more important publications, all of which have been drawn upon freely in the preparation of this book. These are grouped below:

General Works.

Merrill, G. P. Stones for Building and Decoration, New York (Wiley & Sons).

McCourt, W. E. N. Y. State Museum Bull. 100, 1906, and N. J. Geol. Surv., Ann. Rept. 1906. (Valuable papers on fire tests.)

Humphreys. U. S. Geol. Surv., Bull. 370, 1909. (Fire tests.)

Brown, W. M. Stone, June, 1908. (Preservation methods.)

Hermann, O. Steinbruchindustrie und Steinbruchgeologie, Berlin, 1899. (Gebrüder Borntträger.)

[1] Stones for Building and Decoration, 3d ed., p. 454.

Darras, M. Marbrerie, Paris, 1912. (Dunod.)
Davies, D. C. Slate and Slate Quarrying, London, 1899. (Crosby, Lockwood and Son.)
Foerster. Baumaterialienkunde, Leipzig, 1905. (W. Engelmann.)
Pullen, H. W. Handbook of Ancient Roman Marbles, London, 1894. (John Murray.)
Renwick, W. G. Marble and Marble Working, London, 1909. (Lockwood, Crosby and Son.)
Seipp, H. Wetterbeständigkeit der natürlichen Bausteine, Jena, 1900. (H. Costenoble.)

SERIALS.

Stone, a monthly published in New York City.
Baumaterialienkunde, published by Stähle und Friedel, Stuttgart.

SPECIAL PAPERS.

Alabama:

Smith. Eng. and Min. Jour., LXVI, p. 398.
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Watson. U. S. Geol. Surv., Bull. 426, 1910. (Granites.)

Alaska:

Wright. U. S. Geol. Surv., Bull. 345, p. 116, 1908.

Arizona:

Anon. Stone, Aug., 1911. (Marbles.)

Arkansas:

Purdue. Ark. Geol. Surv., 1909. (Slate.)
Hopkins. Ark. Geol. Surv., Ann. Rept. 1890, IV, 1893. (Marbles.)
Williams, J. F. Ark. Geol. Surv., Ann. Rept. 1890, II, 1891. (Igneous rocks.)

California:

Aubury and others. Calif. State Min. Bur., Bull. 38, 1906. (General.)
Eckel. U. S. Geol. Surv., Bull. 225, p. 417, 1904. (Slate.)

Colorado:

Stone, XI, p. 213, 1895.
Lakes, Mines and Minerals, XXII, pp. 29 and 62, 1901.

Connecticut:

Dale. U. S. Geol. Surv., Bull. 484, 1911. (Granites.)

Georgia:

McCallie. Ga. Geol. Surv., Bull. 1, 2d ed., 1904. (Marbles.)
Watson. Ibid, Bull. 9–A, 1903. (Granites and gneisses.)
Watson. U. S. Geol. Surv., Bull. 426, 1910. (Granites.)

Indiana:

Hopkins. Ind. Geol. and Nat. Hist. Surv., 20th Ann. Rept., p. 188, 1896.
Siebenthal. U. S. Geol. Surv., 19th Ann. Rept., VI., p. 292, 1898. (Bedford limestone.) Also 32d Ann. Rept., 1907, p. 321. (Limestone.)
Thompson. Ibid, 17th Ann. Rept., p. 19, 1891. (General.)

Iowa:

Beyer and Williams. Ia. Geol. Surv., XVII, p. 185, 1907. (General.)
Marston. Ibid, p. 54. (Tests.)

Kentucky:
Gardiner. U. S. Geol. Surv., Bull. 430. (Bowling Green limestone.)
Maine:
Dale. U. S. Geol. Surv., Bull. 313, 1907. (Granite.)
Maryland:
Matthews. Md. Geol. Surv., II, p. 125, 1908.
Watson. U. S. Geol. Surv., Bull. 426, 1910. (Granites.)
Massachusetts:
Dale. U. S. Geol. Surv., Bull. 354, 1908. (Granites.)
Michigan:
Benedict. Stone, XVII, p. 153. (Bayport district.)
Minnesota:
Burchard. U. S. Geol. Surv., Bull. 430.
Missouri:
Buckley and Buehler. Mo. Bur. Geol. and Mines, II, 1904.
Montana:
Rowe. Univ. of Mont., Bull. 50.
New Hampshire:
Dale, U. S. Geol. Surv., Bull. 354, 1908. (Granites.)
New Jersey:
Lewis. N. J. Geol. Surv., Ann. Rept., 1908, p. 53, 1909.
New York:
Dale. U. S. Geol. Surv., Bull. 275. (Slate.)
Dickinson. N. Y. State Museum, Bull. 61, 1903. (Bluestone.)
Smock. Bull. N. Y. State Museum, 3.
North Carolina:
Watson, Laney and Merrill. N. C. Geol. Surv., Bull. 2, 1906.
Watson. U. S. Geol. Surv., Bull. 426, 1910. (Granites.)
Ohio:
Orton. Ohio Geol. Surv., V., p. 578, 1884.
Orton and Peppel. Ohio Geol. Surv., 4th Series, Bull. 4, 1906. (Limestones.)
Oklahoma:
Gould and Taylor. Okla. Geol. Surv., Bull. 5, 1911.
Oregon:
Darton. U. S. Geol. Surv., Bull. 387, 1909. (Limestones.)
Pennsylvania:
Hopkins. Penn. State College, Ann. Rept., 1895; Appendix, 1897; also U. S. Geol. Surv., 18th Ann. Rept., V, p. 1025, 1897. (Brownstones.)
Rhode Island:
Dale. U. S. Geol. Surv., Bull. 354, 1908. (Granites.)
South Carolina:
Watson. U. S. Geol. Surv., Bull. 426, 1910. (Granites.)
Sloan. S. C. Geol. Surv., Series IV, Bull. 2, p. 162, 1908.
South Dakota:
Todd. S. Dak. Geol. Surv., Bull. 3, p. 81, 1902.

Tennessee:

Keith. U. S. Geol. Surv., Bull. 213, p. 366, 1903. (Marbles.) See also Merrill's book, mentioned above.

Texas:

Burchard. U. S. Geol. Surv., Bull. 430 F.

Vermont:

Perkins. Report of State Geologist on Mineral Industries of Vermont, 1899–1900, 1903–1904, 1907–1908; also Report on Marble, Slate and Granite Industries, 1898.

Dale. U. S. Geol. Surv., Bull. 404, 1909. (Granite.)

Ries. 18th Ann. Rept. U. S. Geol. Surv. (Marble.)

Virginia:

Watson. Min. Res. of Va., Lynchburg, 1907.

Watson. U. S. Geol. Surv., Bull. 426, 1910. (Granites.)

Washington:

Shedd. Wash. Geol. Surv., II, p. 3, 1902.

West Virginia:

Grimsley. W. Va. Geol. Surv., III, 1905. (Limestones.)

Ibid, IV, p. 355, 1909. (Sandstones.)

Dale. U. S. Geol. Surv., Bull. 275, 1906. (Slate.)

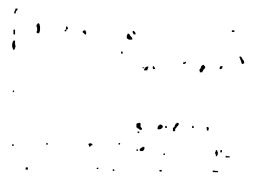
Wisconsin:

Buckley. Wis. Geol. and Nat. Hist. Surv., Bull. IV, 1898.

Wyoming:

Knight. Eng. and Min. Jour., LXVI, p. 546, 1898.

PLATE XIX. — Church in Mexico City constructed of volcanic tuff.



CHAPTER III.

IGNEOUS ROCKS (CHIEFLY GRANITES) AND GNEISSES.

Of the many kinds of igneous rocks, the granites and granite-gneisses are more extensively employed for building stones than any others in the United States.

This is due to several causes, such as wider distribution, more pleasing color and greater regularity of structure and jointing. Syenites are rare and so are the diorites, and hence they are little quarried. Gabbros are not only too dark in color to suit most architects, but it is difficult to supply large-dimension stones of them. They, or certain closely related rocks, have, however, sometimes been used for monumental work. Diabase and basalt are abundant in some regions, the former for example in New Jersey, New York and Connecticut; the latter in Washington and Idaho; both are utilized mainly for paving blocks and road material.

The volcanic rocks, such as rhyolite and trachyte, as well as the consolidated volcanic tuffs, are abundant in the far west, and are of importance in some districts. They are, however, apt to be very porous, and some are sufficiently soft to be cut with a saw. For this reason, selection should be made with care, the softer and more porous ones being used only in mild and dry climates. To the southward in Mexico these soft volcanic materials find great favor for both constructional work and ornamental purposes. Plate XIX shows a church in Mexico City built of this class of stone and brings out well its possibilities.

Since the granites are the most widely used of the igneous rocks, their properties have been more thoroughly investigated in this country, and it is chiefly these which are referred to in the pages immediately following. It may be said, however, that the gneisses and many of the other igneous rocks of granitic

texture are similar to granites in their absorption, crushing strength, transverse strength, fire resistance, etc.

Characteristics of Granites.[1] As commonly used by quarrymen, the term *granite* includes all igneous rocks and gneiss. It seems best, however, to use it in the geological sense, which is more restricted. It may, therefore, be defined as an evenly crystalline, plutonic, igneous rock, consisting of quartz, orthoclase feldspar and mica, hornblende or pyroxene.

There are also varying but usually small quantities of other feldspars, and there are a large number of subordinate accessory minerals, few of which, except the pyrite and garnet, are likely to be recognized by anyone not having a knowledge of mineralogy. Granites may be even-grained or porphyritic in their texture. The former may be subdivided into coarse, medium and fine, in which the feldspars measure two-fifths and one-fifth, and under one-fifth inch respectively.

The average specific gravity of granite is about 2.662, which is equivalent to two long tons, or 4480 pounds per cubic yard, and about 165 pounds to the cubic foot.

The ultimate crushing strength of granite was found by Buckley in Wisconsin ones[2] to vary from about 15,000 to 43,973 pounds per square inch, but 15,000 to 30,000 would be the more usual range.

Elasticity. This property is rarely tested. But specimens from Arkansas, Connecticut, Maine, Minnesota and New Hampshire, showed that pieces with a gaged length of 20 inches, and a diameter of 5.5 inches at the middle, when placed under a load of 5000 pounds per square inch, compressed from 0.0108 to 0.0245 inch. This resulted in a lateral expansion of from 0.005 to 0.007 inch, and gave ratios of lateral expansion to longitudinal compression ranging from 1 : 8 to 1 : 47 (Test of Metals (1895), 1896, pp. 339–348).

Flexibility. Granite, in spite of its apparently rigid character, is flexible in sheets of sufficient thinness and area. Dale states

[1] For an excellent discussion of the properties of granites see Dale, U. S. Geol. Surv., Bull. 313.

[2] Bull. Wis. Geol. and Nat. Hist. Surv., 4, p. 361, 390.

that sheets ½ inch thick and 4 feet long, from a Maine quarry, were flexible, but suggests that this flexibility may have been due to the partially disintegrated character of the stone.[1]

Expansibility. This is referred to under *permanent swelling.*

Porosity. The porosity of granites is usually small. Buckley gave that of 14 Wisconsin granites as ranging from 0.17 to 0.392 per cent, while in Maryland granites, according to Merrill, it is from 0.196 to 0.258. Granite also absorbs a slight amount of water, usually under 1 per cent if the stone is fresh.

Fire Resistance. Granite spalls off badly under the combined influence of fire and water, which may be due to the differential expansion and contraction of the outer and inner portions of a block. It may also be connected with the vitreousness of the quartz and the presence of liquids contained in microscopic cavities of the quartz.

Chemical Composition. The two following analyses represent, I, the average chemical composition of granite as given by Merrill and, II, the average composition of 21 Georgia granites given by Watson:

	I.	II.
Silica	72.00	69.97
Alumina	15.07	16.63
Iron oxide	2.22	1.28
Magnesia	0.50	0.55
Lime	2.00	2.13
Potash	4.12	4.71
Soda	2.90	4.73
Loss on ignition	1.19	.....

Classification. For scientific purposes granites might be classified according to the less essential mineral constituents, as mica, hornblende and augite, or a more complex scheme classifies them according to their mineral and chemical composition.

For economic purposes, granites may be classified according to their texture, as even-grained or porphyritic, or as coarse, medium and fine. Again color and shade may be used as the basis for grouping. Some may prefer a grouping according to uses. None of these are wholly satisfactory.

[1] U. S. Geol. Surv., Bull. 313, pp. 22 and 151, 1907.

Structure of Granites. Some granites may indicate the direction in which the molten rock flowed before cooling, by streaks or sheets of mica scales parallel to the direction of the line of contact between two granites. The character is a purely local one, and is not to be confused with gneissic structure (Dale).

The *rift* is an obscure foliation, either vertical (or nearly so) or horizontal, along which the granite splits more readily than in any other direction, while the *grain* is a direction at right angles to the rift, along which the stone also splits, but less readily.

Microscopic examination of the stone shows that the rift may be due to microscopic faults which may cut through both the quartz and feldspar grains.

Rift and grain are not necessarily pronounced; indeed, either or both may be feeble or absent. The rift may sometimes change its course, and this the quarryman terms the *run*.

Cut-off or hardway is the quarrymen's term for the direction along which the granite must be channeled because it will not split.

Sheets or *beds* are terms used to designate the division of granite by joint-like fractures which are variously curved or nearly horizontal, and generally parallel with the surface. They sometimes become thicker.

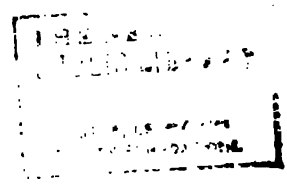
Joints are found in almost every granite quarry. In some they are regular, but in others exceedingly irregular, so that the granite is broken up into a number of polygonal blocks. Where the granites have been weathered along such joints the blocks resemble boulders, hence the name boulder quarries. Such quarries are more common in the southern states than in the northern ones.

Dale states that in some quarries the "granite near the surface acquires a marked foliation, which appears to be parallel to the sheet structure, and possibly to the rift. This foliation is known by quarrymen as *shakes*. It occurs both at the top and at the bottom of the sheet, through a maximum thickness of six inches. It is coextensive with the discoloration known as sap and occurs at many places near vertical joints."

Knots are segregations of the darker minerals forming dark, unsightly spots in granite, and may cause the rejection of those portions of the stone in which they occur.

PLATE XX, Fig. 1. — Granite quarry, Hardwick, Vt.

PLATE XX, Fig. 2. — Granite quarry at North Jay, Me. (Photo loaned by Maine and New Hampshire Granite Company.)



Inclusions. Many granites contain angular or irregular fragments of other rocks, such as schists, gneisses or even other granites, which became incorporated in the granite itself during its intrusion. Those portions of the rock containing them are usually discarded.

Dikes. In some granite quarries the stone is traversed by dikes of other igneous rock, such as diabase, or in some cases pegmatites, the latter being regardable as a very coarse-grained granite. These dikes may be both large and small, and blocks containing them are of no value for structural purposes.

Black Granites. This term, suggested by Dale, is a good one to use for commercial purposes and may include a variety of igneous rocks of prevailingly dark color, such as gabbros, diorites, diabases, etc. Their characters have been previously referred to.

The black granites correspond to the fine and medium-grained granites in their texture, but, aside from their greater toughness, they probably vary but little in their physical properties from granites of the same grade and texture. We are not so familiar with their physical properties, for the reason that their use for structural purposes is limited, and they have not been studied in detail. The weight per cubic foot of the black granites is greater than that of the common granites, the gabbros ranging in specific gravity from 2.66 to about 3 and the diabases from 2.7 to 2.98, while the diorites average about 2.95. Their chief use is for monumental work.

Tests of Granite. These may include the ordinary tests made on all building stones such as the determination of the crushing strength, transverse strength, absorption, porosity, specific gravity, fire test, freezing test, coefficient of expansion, presence of calcium carbonate and ability to take a polish. These have been discussed in the preceding chapter.

A number of tests of granite have been published, but unfortunately most of them are only determinations of the crushing strength and absorption. It is, therefore, difficult to present a large series of complete tests. The following, however, will serve to give some idea of the variation shown by different granites:

630122

TESTS OF GRANITES.

Locality.	Size of cube.	Position.	Crushing strength, lbs. per sq. in.		Modulus of rupture.		Sp. gr.	Per cent absorption.	Weight per cu.ft.	Remarks.
			Aver.	Max.	Aver.	Max.				
Burnet Co., Tex.	4×2×2.11		11,891				2.625	0.0000	163.64	Red.
Llano Co., Tex.	1×1×1		11,990				2.64	0.0028	163.49	Red; Teich quarry.
Burnet Co., Tex.	1×1×1		9,340				2.76	0.0021	170.97	Light gray; Ueberall quarry.
Llano Co., Tex.	1×1×1		15,300				2.67	0.0036	164.73	"Opal" granite.
Rockport, Mass.	4×4×4			20,716 17,772	2410				161.5	Pigeon Hill quarry.
Becket, Mass.				25,350 28,841			2.688	0.0022		
Quincy, Mass.			17,750				2.6		166.2	
Graniteville, Mo.			19,410	23,726						Red granite.
Syenite, Mo.			18,236	23,703						Gray granite.
Syenite, Mo.			22,883	31,550						Red granite.
Branford, Conn.				22,447	1415				165.4	
Lithonia, Ga.	2×2×2			17,413			2.686	0.052	167.9	
Stone Mountain, Ga.				28,130 12,190			2.686	0.067	167.9	These represent extremes.
Fairfield Co., S. C.	3.5×3.4×3.5			31,980			2.62	0.360		Rion quarry.
Amberg, Wis.				21,299			2.713	0.04	169.05	
Granite Heights, Wis.				22,954			2.631	0.14	163.61	
Montello, Wis.				43,639		3909.7	2.641	0.079	164.28	
Berlin, Wis.				31,300			2.643	0.143	164.20	
Little Rock, Ark.	4×4×4		19,590		1704					
Rockville, Minn.	4×4×4		18,121		1423					
Richmond, Va.	4.03×3.9×4			23,446						
Index, Wash.			15,200	16,610			2.74	0.48	167.4	Per cent porosity, 1.308.
Port Deposit, Md.		Bed	15,000	19,750			2.72	0.23	170	
Port Deposit, Md.		Edge		13,100						
St. Cloud, Minn.		Bed		16,000			2.69	0.4	168	
Westerly, R. I.		Bed		14,687			2.67		166.9	
Mt. Airy, N. C.			20,407					0.4		
Granite City, Okla.			11,200 16,800				2.63			

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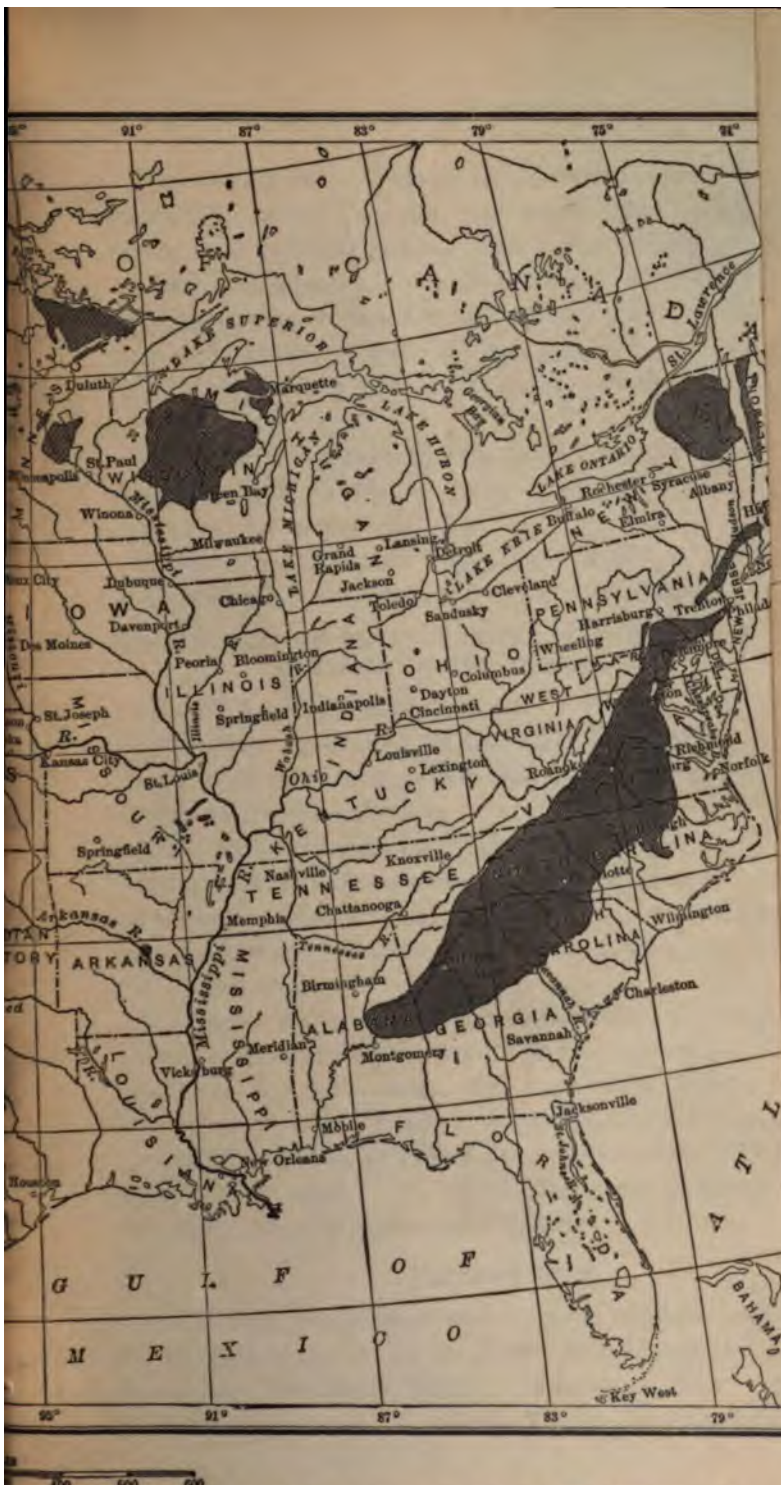
PLATE XXI. — Map showing distribution of igneous rocks and gneisses



ited States. (After G. P. Merrill, "Stones for Building and Decoration.")

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Uses of Granite. Granites, on account of their usually great durability, variety of color, and texture are among our most widely used building stones. The coarser and medium-grained ones are best adapted to massive masonry work, while the finer and even-textured ones are most sought after for monumental work and structural work of finer lines. The darker granites often give excellent contrast between polished and hammered surfaces.

Certain ones, however, like the Quincy, Mass.; North Jay, Me.; Westerly, R. I.; Barre, Vt., and others, have been especially much used for monuments.

At almost every granite quarry there is more or less small-sized stone, which is used for paving blocks, and crushed stone.

DISTRIBUTION OF IGNEOUS ROCKS (CHIEFLY GRANITES) AND GNEISSES IN THE UNITED STATES.

Granite forms an important source of building stone, somewhat widely distributed in the United States, but probably 70 per cent of that quarried comes from the eastern United States, where the extensive deposits, owing to their favorable location for working and shipment, together with their nearness to large markets, have been developed on an enormous scale. The other kinds of igneous rock are used to a much more limited extent than the granite. Gneisses, usually of granitic composition, are also widely employed in the eastern states.

The areas which may be considered are: (1) Eastern Belt extending from Maine, southwestward to eastern Alabama. (2) Minnesota-Wisconsin Area. (3) Southwestern Area including isolated districts in Missouri, Arkansas, Oklahoma and Texas. (4) Cordilleran Area including parts of Colorado, California and other western states. (5) Black Hills Area of South Dakota, with a great mass of undeveloped granite.

EASTERN BELT.

In this belt, whose limits were referred to above, granite quarries have been opened up in Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, Connecticut, New York, New Jersey, Pennsylvania, Maryland, Virginia and Georgia. Those

of the New England area are specially prominent. While they are nearly all true granites mineralogically, those in the southern half of the belt especially often show a gneissic structure. No attempt will be made here to describe all the quarries, but simply to mention the more important localities in each state, with a brief statement of the character of the stone.

References are given in the bibliography at the end of Chapter II.

MAINE.

With the exception of the important quarries of Hallowell in Kennebec County, North Jay in Franklin, and a few minor ones, all the Maine granite quarries are located along the seaboard, but the industry has its center in Penobscot and Blue Hill bays and the islands around them.

There are said to be about 12 quarries in black granite, located in York, Lincoln, Penobscot and Washington counties, and the product of these is used in comparatively small amounts for expensive work.

The characteristics of the Maine granites may be summarized as follows:

North Jay. A biotite-muscovite granite, known as "White granite," of fine, even-grained texture. It does not take a very good polish, owing to the abundance of mica scales. The product is used for monuments and buildings, the chief market being in the west.

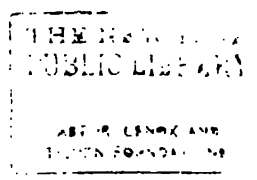
Examples. — General Grant's tomb, Riverside Drive, New York City; Hahnemann monument, Washington, D. C.; Chicago and Northwestern Railroad Building, Chicago; Western German Bank, Cincinnati, Ohio; Marshall Field store, Chicago. The refuse is used for rough stone, paving blocks and crushed stone.

Crotch Island. A biotite granite, of lavender, medium gray color, and coarse but even-grained texture, whose chief use is in massive construction work, especially in New York City.

Examples. — Blackwells Island Bridge and Ninth Regiment Armory, New York City; Post Office, Lowell, Mass.; Steps of Library, Columbia University, New York City.

Hallowell. Biotite-muscovite granite, light gray shade and fine texture, with porphyritic feldspars of about one-quarter inch diameter. It takes a fine polish, and the face so treated has a

PLATE XXII. — Cleveland Trust Company, Cleveland, Ohio, constructed of North Jay, Me., granite.
(Photo, Maine and New Hampshire Granite Company.)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bluish tinge. It is used for buildings and sculpture, and is well adapted to statuary and delicate ornamental work.

Examples. — Albany Capital, Albany, N. Y.; Hall of Records (including statuary), New York City; Masonic Temple, Boston, Mass.; Illinois Trust Company, Chicago, Ill.; Northwestern Insurance Company building, Milwaukee; Statuary on Plymouth monument, Mass.; Soldiers' monument, Gettysburg; Suffolk Savings Bank, Boston. The waste is used for paving blocks.

Vinalhaven and Hurricane Islands. These and the adjacent islands are known collectively as the Fox Islands, and their granite as the Fox Island granite. The rock is mostly a biotite-granite, pinkish buff, medium gray in color, and of coarse, even-grained texture. It takes a good polish but the size of the mica plates is not favorable to its being durable on continued exposure. The stone is used for docks, bridges, piers, buildings and monuments.

Examples. — New Post Office, Washington, D. C.; Masonic Temple, Philadelphia; General Wool monument, Troy; Manhattan Bank, New York City.

The Palmer or Wharf quarry of this region supplied 8 columns, 51½ to 54 feet by 6 feet, for the Cathedral of St. John the Divine in New York City. These were to have been cut in one piece, with the longer axes at right angles to the rift. In the lathe, however, the strain came upon the weakest part of the stone, and as it had been subjected to torsional strain by the application of rotary power from one end only, it broke diagonally. The columns therefore, had to be made 26 foot lengths.

Red Beach. A biotite-granite of bright pink color and medium, even-grained texture. It takes a high polish of good durability, and is the brightest red granite occurring in Maine, being shipped all over the United States for monumental work.

Examples. — Part of American Museum of Natural History, New York City; Pedestal of General Grant Monument, Galena, Ill.

Addison. The stone quarried here is an hypersthene-olivine gabbro of nearly black color, and the polished surface is jet black mottled with a little white. In some quarries a somewhat lighter colored variety is obtained.

The stone shows excellent contrast — the almost white hammered surface comparing well with the dark polished face. It is used for monuments and interior decoration.

Examples. — Base of wainscoting, Philadelphia City Hall; Danforth Monument, Morristown, N. J.; Zeller Monument, Lewisburg, Pa.: center monument at Greenwood Cemetery, Brooklyn, N. Y.

Jonesboro. A biotite granite of grayish-pink color and slightly coarse, even-grained texture. The stone takes a good polish of durable nature.

Examples. — Custom House and Post Office, Buffalo, N. Y.; Custom House and Post Office, Fall River, Mass.; Western Savings Bank Building, Philadelphia; Pullman Office Building, Chicago, Ill.; Wellington Building and Jordan Marsh & Company Building, Boston, Mass.; Fidelity and Trust Building, Newark, N. J.

The following additional examples of other granites may simply be mentioned.

Blue Hill. Mess Hall, Soldiers Home, Washington, D. C.; Manhattan Trust Building, New York City; Post Office, Harrisburg, Pa.

Brookville. Bronx Court House, New York City; Post Office, Middletown, N. Y.

Dix Island. New York Post Office; Philadelphia Post Office; Treasury Building, Washington.

Clark's Island. Post Office, Hartford, Conn.; Atlantic Trust Co., New York City.

Machias. Elliot Hall, Cambridge; Chapel, Mt. Hope Cemetery, Bangor, Me.

Pleasant River. Wainscoting, Philadelphia City Hall.

Stonington. Several bridges across Harlem River, New York City.

Classification of Maine Granites. Dale gives the following economic classification of Maine granites.

1. Reddish (medium to coarse).
   Light: Wells, Black Island, Mount Desert.
   Swans' Island (Toothachers' Cove).
   Bright: Redbeach.
   Dark: Shattuck Mountain, Redbeach, Jonesport (Head Harbor and Hardwood Islands), Marshfield, Black Island, Mount Desert, Jonesboro.
2. Pinkish buff (medium to coarse).
   Vinalhaven (in part), Hurricane Island, High Island, Dix Island, Swans Island, Biddeford, Stonington (Deer Isle, Crotch Island, Green Island).
3. Light lavender (medium to coarse).
   Stonington, Crotch Island, Deer Isle, Moose Island, Jonesboro.
4. Gray (medium to coarse); black and white, latter dominant, strong contrasts. Feldspar in some rocks, slightly bluish.
   Biddeford, Kennebunkport, Blue Hill, South Thomaston, Guilford Norridgewock, South Brookville.

5. Gray, with isolated lighter crystals. Frankfort, Searsport, Blue Hill, Dedham.
6. Buff (medium to coarse).
   Millbridge, Mount Desert, Brooksville, Sedgwick.
7. Greenish gray (medium coarse).
   Mount Desert, Alfred.
8. Black and white (medium texture, black dominant).
   Spruce Head, Hartland, Woodstock, Norridgewock.
9. Gray, weak contrasts (medium to coarse texture).
   Sullivan, Franklin.
10. Muscovite, white mica conspicuous (medium texture).
    Fryeburg, Oxford, Bradbury.
11. Fine textured (light to medium gray).
    Jay, Pownal, Swanville, Lincoln, Hallowell, Freeport, Frankfort, Blue Hill, Clark Island, Long Cove, Brunswick, Crotch Island, Waldoboro, Norridgewock.
12. Very coarse (gray or pinkish buff).
    Stonington, Dedham, Franklin.
13. Paving (fine, with isolated crystals).
    Vinalhaven, Mount Desert.
14. Black (fine to coarse). Black and black speckled.
    Vinalhaven, Addison, Calais.
    Greenish black.
    Belfast, South Berwick, Hermon.
    Dark gray.
    Sullivan, Barleyville, Redbeach, Calais, St. George, Round Pond quarry.
    Medium gray.
    Round Pond quarry, Whitefield.

NEW HAMPSHIRE.

The commercial granites of New Hampshire afford a variety of rocks, as can be seen in the summarized table. The most important constructional ones are those of Concord, Fitzwilliam, Marlboro, Lebanon, Canaan and Redstone, while the monumental granites include those of Fitzwilliam, Troy, Milford and Brookline.

The most notable structure of New Hampshire granite erected, according to Dale, is the library of Congress.

Some of the more important granites are referred to in detail below, while all are mentioned in a summarized table prepared by T. N. Dale, given on a later page.

Concord. A muscovite-biotite granite, of medium and bluish gray color, and a texture from fine to medium though somewhat porphyritic. It takes a fair polish, but has rather too much

mica. Considerable contrast is obtained between the rough and hammered surface.

Examples. — Blackstone Library, Chicago; Christian Science Church, New York City; German-American Savings Bank, Pittsburg, Pa.; outer walls, Congressional Library, Washington; City Hall and Christian Science Church, Boston; Post offices at Lincoln, Neb.; Adrian, Mich.; and Hammond, Ind.

Milford. Quartz monzonite, of light, medium and dark gray shades, in places of a slight bluish, pinkish or buff tinge, and always spangled with black mica. Texture, even-grained, very fine to fine. The finer ones are properly monumental granites, take a high polish and give good contrast. The finer ones show a uniformity and delicacy of shade and tint. The coarser ones are for constructional work.

Examples. — Majestic Theatre, Chicago, Ill.; east front Treasury Building, Washington, D. C.; Post Office, Lawrence, Mass.

Conway. The granites are all coarse, constructional ones, mostly pinkish, mottled with gray and spotted with black. They are biotite or biotite-hornblende granites. Some are greenish.

The Redstone quarry rock takes a high polish, but the large size of the mica scales is not favorable to the durability of same under long-continued exposure. This is mainly a constructional granite.

Examples. — First National Bank, Chicago; Franklin Savings Bank, New York City; Union Station, Pittsburg; First and Fourth National Banks, Cincinnati, with polished columns; High School, Springfield, Mass.; the Redstone green, Fidelity Mutual Life Insurance Building, Philadelphia; polished columns on Northwestern Guarantee Loan Company's Building, Minneapolis.

Auburn. This granite belongs to the same general granite area as the Concord. The granite, "deep pink Auburn," is a quartz monzonite of medium pink buff color with fine, black dots. The texture is fine. The stone takes a fair polish, and the hammered face by its lightness makes good contrast with rough and polished surfaces.

Troy. This is similar to the North Jay, Me., which see.

Fitzwilliam. Muscovite-biotite granite, light, bluish gray color, and even, fine-grained texture. Used mainly for buildings and monuments.

Some takes a good polish.

Examples. — City Hall, Newark, N. J.; approaches and bases of First Church of Christ, Scientist, Boston; Smith Mausoleum, Paducah, Ky.; Tanner Mausoleum, Springfield, Ill.

The "snow-flake" granite from here is a biotite-muscovite granite, of light to medium gray shade, and porphyritic texture. It is used for buildings and monuments.

Examples. — Art Museum, Toledo, Ohio; Law Building, Iowa University; Post offices at Muskegon, Mich.; Grand Island, Neb.; Bedford, Ind.; Devil's Lake, N. Dak.; Ithaca, N. Y.

Other grades from here are the "Marlboro," the "Troy white." Latter widely used, and lends itself well to carving.

Examples. — Bank of Pittsburg, Pittsburg, Pa.; Metropolitan Savings Bank, Baltimore, Md.; Steps and approaches to Library of Congress, Washington, and New York Library; Mark Hanna mausoleum, Cleveland, Ohio.

Mascoma Granite, near Enfield. A biotite gneiss of light buff-gray color speckled with black, and of even-grained, somewhat gneissoid, coarse texture. It is a constructional stone, somewhat resembling that from Milford, Mass., takes fair polish and face shows some magnetite.

Examples. — Plain Dealer Building, Cleveland, Ohio; Carnegie Institute, Pittsburg, Pa.; Royal Bank of Canada, Winnipeg, Man.; Agricultural National Bank, Pittsfield, Mass.; Jamestown Monument, Jamestown Id., Va.

Classification of New Hampshire Granites. The following classification of the commercial granites of New Hampshire is given by Dale.

CLASSIFICATION OF NEW HAMPSHIRE GRANITES.

CONSTRUCTIONAL.

Locality.	Trade name.	General color and shade.	Texture.	Petrographic name.
Concord (various quarries)	Concord	Medium bluish gray	Fine, medium, somewhat porphyritic.	Muscovite-biotite granite.
Troy (Troy quarry)	Troy white	Light, inclining to medium bluish gray.	Fine	do
Fitzwilliam (Webb quarry)	Fitzwilliam Webb	Light, very bluish gray	do	do
Fitzwilliam (Holman quarry)	Fitzwilliam	Light bluish gray	Medium, inclining to fine	do
Fitzwilliam (Silver White quarry)	Silver White	do	Very fine (average diameter, 0.0068 inch).	Biovite-muscovite granite.
Fitzwilliam (Snow Flake quarry)	Snow Flake	Light, inclining to medium gray	Porphyritic with fine matrix	do
Marlboro (Marlboro quarry)	Marlboro	Light inclining to medium, very bluish gray.	Fine	do
Stark (Dawson quarry)	Stark	Medium pinkish gray	Medium	Biotite granite.
Canaan (Mascoma quarry)	Mascoma	Light buff-gray	Gneissoid, coarse	Biotite granite gneiss.
Lebanon (Lebanon quarry)	Lebanon pink	Light, faintly pinkish-greenish gray	do	Epidotic biotite granite gneiss.
Redstone (Redstone quarry)	Redstone red	Light pink mottled with dark gray	Coarse	Biotite granite.
Madison (Fletcher & Lahey quarry)	Madison	Light pinkish gray mottled with dark purplish gray.	do	do
North Conway (White Mountain quarry).	North Conway	Medium pinkish buff-gray	do	do
Kilkenny (Kilkenny quarry)	Kilkenny	Dark olive-green	Medium	Augite-biotite granite.
Milford (Carlton quarry)	Milford building	Medium pinkish gray	Porphyritic	Quartz monzonite, probably.
Milford (Lovejoy quarry)	do	Light gray	Fine inclining to medium	Quartz monzonite.
Milford (Kittredge and Pease quarries).	do	Light gray with very slight bluish tinge.	do	do
Milford (Pease quarry)	Milford building, pink	Light buff-gray, some slightly pinkish.	do	do

MONUMENTAL.

Fitzwilliam (Silver White quarry)	Silver White	Light bluish gray	Very fine (average diameter, 0.0068 inch).	Biotite-muscovite granite.
Troy (Troy quarry)	Troy white	Light, inclining to medium bluish gray.	Fine	Muscovite-biotite granite.
Haverhill (Pond Ledge quarry)	Pond Ledge gray	Light, inclining to medium gray	Fine, but with sparse porphyritic feldspars.	Biotite-muscovite granite.
do	Pond Ledge pink	Light pinkish gray	do	do
Sunapee (Spectacle Pond quarry)	Spectacle Pond	Light buff-gray	Fine	do
Sunapee (Perry quarry)	Light Sunapee	Light, slightly bluish gray	do	With biotite and muscovite in about equal amounts.
Brookline (O'Rourke quarry)	Brookline	Medium buff-gray	do	Quartz monzonite.

CLASSIFICATION OF NEW HAMPSHIRE GRANITES (Continued).

MONUMENTAL (Continued).

Locality.	Trade name.	General color and shade.	Texture.	Petrographic name.
South Brookline (Fessenden quarry).	Brookline	Medium, faintly pinkish gray	Fine (average diameter, 0.0097 inch).	Quartz monzonite
Milford (Young quarry)	Dark blue New Westerly.	Dark gray (smoke color)	Fine (average diameter, 0.0084 inch).	do
Milford (New Westerly quarry)	New Westerly blue	Medium, slightly bluish gray	Fine (average diameter, 0.009 inch).	do
Milford (Tonella, old quarry)	Milford	Light gray	Fine (average diameter, 0.011 inch).	do
Milford (Comolli and Paradis quarries).	do	Light, inclining to medium bluish gray.	Very fine	do
Milford (Souhegan quarry)	do	Dark gray with very slight pinkish tinge.	Fine	do
Milford (Bishop quarry)	do	Light gray, faintly cream colored	do	do
Auburn (Perry quarry)	Deep pink Auburn	Medium pink-buff	do	do

INSCRIPTIONAL.

Sunapee	Black pearl	Very dark bluish gray	Fine to medium	Quartz diorite.
Milford (Young quarry)	Dark blue New Westerly.	Dark gray (smoke color)	Fine (average diameter, 0.0084 inch).	Quartz monzonite.
Milford (Souhegan quarry)	Milford	Dark gray with very slight pinkish tinge.	Fine	do

POLISH.

Madison (Fletcher & Lahey quarry).	Madison	Light pinkish gray mottled with dark purplish gray.	Coarse	Biotite granite.
Redstone (Redstone quarry)	Redstone red	Light pink mottled with dark gray.	do	do
do	Redstone green	Dark yellow greenish gra	do	Biotite-hornblende granite.

CURBING AND TRIMMING.

Rochester (Langmaid quarry)	Rochester	Very light gray	Medium	Biotite granite.
Manchester (Kennard Ledge quarry).	Kennard ledge	Medium buff-gray	do	do
Manchester (Bodwell quarry)	Bodwell quarry	Light, inclining to medium gray	do	do
Nashua (Stevens quarry)	Nashua	Light gray	Gneissic; medium	Muscovite-biotite granite gneiss.
Allenstown (Bailey quarry)	Allenstown	do	Medium	Muscovite-biotite granite.
Hooksett (Shirley quarry)	Hooksett	do	do	do

VERMONT.

The commercial granites of Vermont are of three kinds: Biotite granite, quartz monzonite and hornblende-augite granite. To the first class belong those of Woodbury, Newark and most of Barre, to the second those of Bethel, Randolph, Rochester, Calais, Derby, Dummerston, Hardwick (Buffalo Hill), Kirby, Groton, Topsham, and some in Cabot. To the third, those of Mount Ascutney in Windsor. The Ryegate ones belong to both the first and second.

A few may be mentioned briefly:

Hardwick. The granite from the Buffalo Hill quarry, known as the "Dark Blue Hardwick" is a quartz monzonite of dark gray shade, a little darker than "Dark Barre" and a little lighter than "Dark Quincy." The texture is medium. It is a bright granite with strong contrast between the white feldspar and black mica and takes a fair polish. It hammers light, offering a marked contrast to the polished surface. The latter shows some pyrite and magnetite.

Bethel. This is known commercially as the "Bethel White Granite" and the "Hardwick White Granite." It is a quartz monzonite of very light color, medium texture, and relatively hard. It takes a high polish.

Examples. — Wisconsin State Capitol, Madison, Wis.; Title Guarantee and Trust Co.'s Building, New York City; Old Colony Trust Company's Building, Boston, Mass.; Union Station, Plaza, Washington, D. C.

Barre. To the southeast and northeast of the city of Barre there are about sixty quarries producing the "Barre" granite. The stone is a biotite granite which owes its different shading partly to the varying content of biotite, and partly to different degrees of alteration of the feldspar.

Dale names the following shades: (1) Very light gray (Wheaton quarry), equivalent to that of North Jay, Me.; (2) Light, inclining to medium, slightly bluish gray (Jones light quarry), between that of North Jay and of Hallowell, Me.; (3) Light, medium bluish gray (Smith upper quarry), between that of Hallowell, Me., and Concord, N. H.; (4) Medium bluish gray (Duffee quarry), a trifle darker than "Concord granite;" (5)

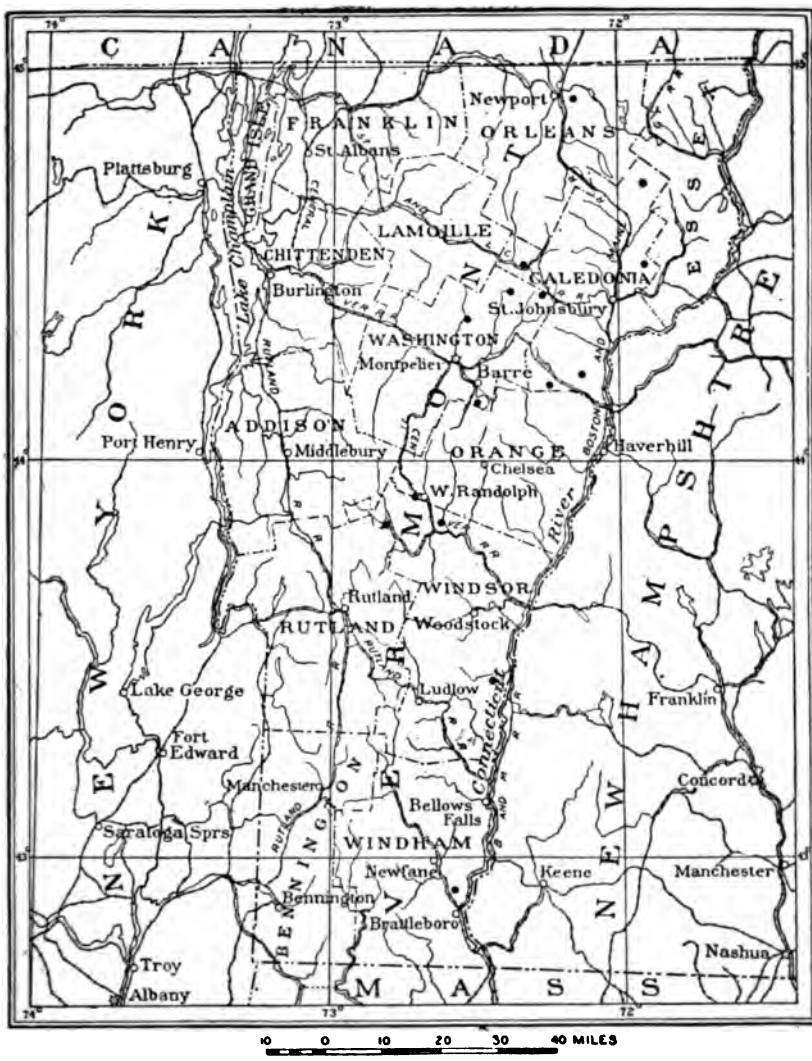

Plate XXIII. — Map of Vermont showing granite centres and prospects. (After Dale, U. S. Geol. Surv., Bull. 404.)

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ASTOR, LENOX AND
TILDEN FOUNDATIONS

Dark, inclining to medium bluish gray (Bruce quarry); (6) Dark bluish gray (Marr & Gordon quarry); (7) Very dark bluish gray (Marr & Gordon quarry knots), equivalent to " Dark Quincy." The chief production is of 3, 4 and 5.

Barre granite is used mainly for monumental purposes, a small quantity only being employed for constructional work. The light, medium and dark monumental granites do not afford strong mineral contrasts in the rough, but polishing improves this. The " light Barre" is never polished, but hammered, because of the poor contrast between polished and hammered surface. The dark is often used in polished form.

The Barre stone is perhaps one of the most extensively used in the United States and some large pieces have been taken out. Professor Perkins mentions one that was 95 feet long, 45 feet wide and 25 feet thick. Needless to say, this was not removed from the quarry in one piece. The largest finished pieces ever shipped from Barre were sent to Wheaton, Ill., to be used as roof pieces for a mausoleum. Each was 35 feet long, 9 feet 4 inches wide, and 1 foot 4 inches thick. Another piece quarried was 51 by 4 by 4 feet, and was cut into a shaft which is now in Greenwood Cemetery, Brooklyn, N. Y.

Examples. — Calhoun Monument, Lexington, Ky.; Ohio and Iowa State Soldiers' Monuments, Chattanooga, Tenn.; State Soldiers' Monument, York, Pa.; Hearn Monument, with monolithic spire, 53 by 4 by 4 feet, Woodlawn, N. Y.; Gary Mausoleum with roof stones of the "light," 35 feet by 9 feet 6 inches, by 1 foot 6 inches each, Wheaton, Ill.; First North Dakota Soldiers' Memorial, St. Paul, Minn.; Cluett Obelisk, with 44-foot shaft and pedestal, Troy, N. Y.; Holthaus Monument, St. Louis, Mo.; Columns and capitols for Flood Mausoleum, San Francisco, Cal.

Woodbury. This district supplies biotite granites of more or less bluish gray color, varying from dark to light shades, and very fine to medium texture.

Examples. — Pennsylvania State Capitol, Harrisburg, Pa.; Cook County Court House, Chicago, Ill.; Syracuse University Library, Syracuse, N. Y.; Commonwealth Trust Co., Pittsburg, Pa.; Post Office, Des Moines, Ia.

Windsor. A green granite found on Mount Ascutney and classed mineralogically as a hornblende-augite granite. It is of dark olive-green color and medium texture. The stone takes a high polish and shows excellent contrast between the polished

and hammered surface; indeed it is one of the handsomest granites quarried in the United States.

Examples. — Sixteen polished columns (24 feet 9½ inches by 3 feet 7 inches) in Columbia University Library; Monument to General Gomez in Cuba; a die in the Bennington monument; thirty-four large columns in the Bank of Montreal; columns and die of W. C. T. U. fountain, Orange, Mass.; columns for interior of Temple of the Scottish Rite, Washington, D. C.

MASSACHUSETTS.

The igneous rocks and gneisses quarried in Massachusetts, and which could be grouped under the name of commercial granite, present considerable variety as to kind, texture and color. The important constructional ones are those of Milford, Fall River, New Bedford and Rockport. The Quincy granite in polished form is widely known because of its value for monuments.

The most important granite quarrying centers are around Quincy, Rockport, Milford and Chester.

Milford. A pink or pinkish gray or even greenish gray biotite granite, with spots of black mica, and of medium to coarse texture. The stone has a slightly gneissoid appearance, so that the spots are larger when the granite is cut parallel to the planes of foliation than when the faces intersect it at right angles. It takes a good polish and is extensively used for exterior and interior structural work.

Examples. — Eighty-four 31-foot sectional columns for the new Pennsylvania Railroad Station, New York City; Twelfth Street Station, Illinois Central Railroad, Chicago; John Hancock Insurance Company, Boston, Mass.; Rochester Safe Deposit and Trust Company, Rochester, N.Y.; Riggs National Bank, Washington, D. C.; Interior N. Y. Central R. R. Station, Albany, N. Y.

Rockport. The quarries are on Cape Ann, Essex County, Massachusetts. The Rockport granite is of two sorts, viz., gray and green. The gray granite, the most abundantly known commercially, is a hornblende granite of medium gray color, spotted with black, and of a medium to coarse but even-grained texture. It is said to be a hard granite, due perhaps to its higher percentage of quartz, and takes a good polish.

The green granite, which is also hornblendic, is of a somewhat dark, olive-gray color, spotted with black. The texture is medium to coarse, though even-grained. This stone, though dark gray when first quarried, becomes greenish after an exposure of

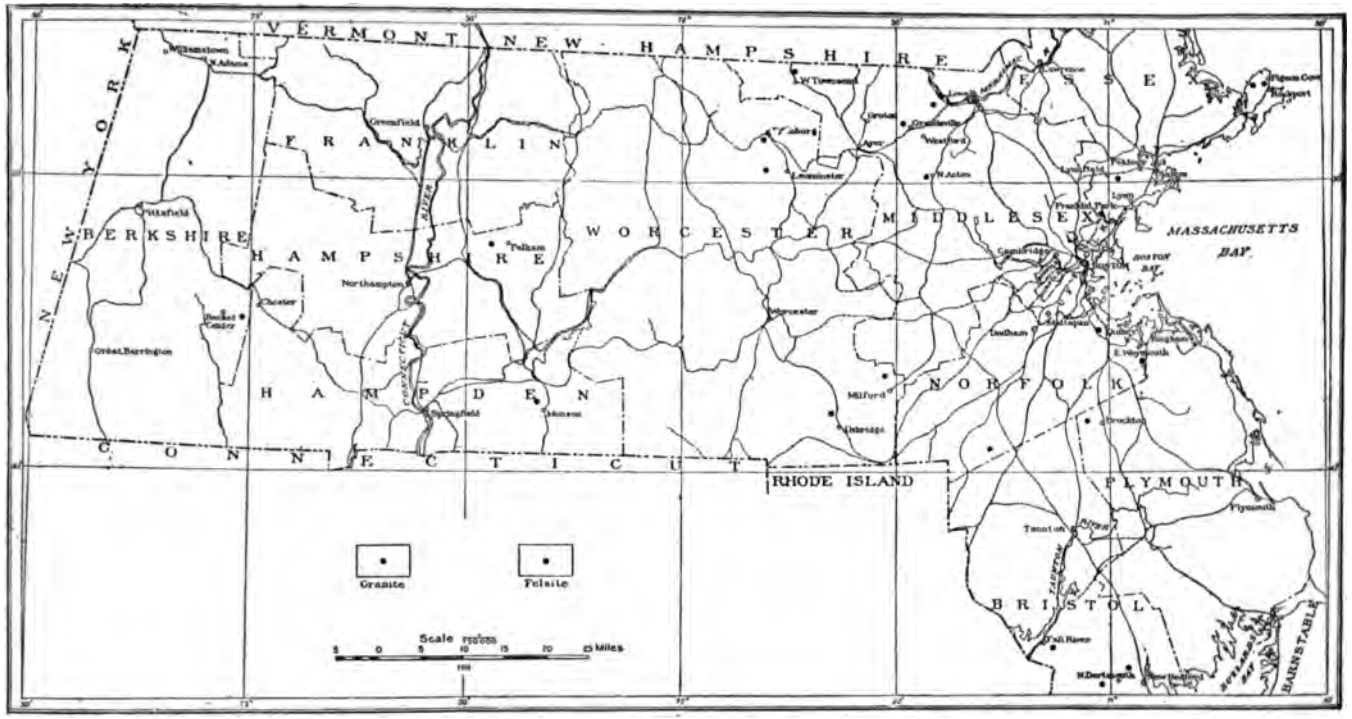
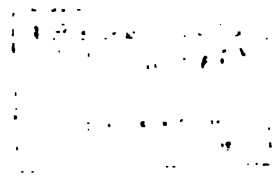


PLATE XXIV. — Map of Massachusetts, showing quarrying centers. (After Dale, U. S. Geol. Surv. Bull. 470.)

PLATE XXV, Fig. 1. - Milford, Mass., granite, showing speckled appearance, caused by biotite scales against lighter background of quartz and feldspar.

PLATE XXV, Fig. 2. — Battle Monument on Lookout Mountain, Chattanooga, Tenn., constructed of Milford pink granite. (H. Ries, photo.)



3 to 4 hours to the rain. It also fades slightly on continued exposure to the air. The stone takes a high polish, but shows less contrast between hammered and polished surface than the gray.

Examples. — Red: Real Estate Trust Company's Building, Philadelphia; American Baptist Publication Building, Philadelphia; Interior of Suffolk County Court House, Boston; Siegel Cooper Company Building, New York City.

Gray Granite: Boston Post Office; Baltimore Post Office; Suffolk County Court House, Boston; National City Bank Building, New York City; Polished columns, Madison Square Presbyterian Church, New York City.

Green Granite: Madison Avenue Church columns, New York City; Wainscoting and stairways to the Towers of Philadelphia Public Buildings; Logan Monument, Chicago; two large polished bowls, Plaza Improvement, Union Station, Washington, D. C.

Chester. A muscovite-biotite granite, of bluish-gray color and somewhat indefinite texture. It takes a fair polish and the hammered surface is light. Two varieties, the *Chester dark* and *Chester light*, are recognized. It is used chiefly for monuments, especially in Pennsylvania, New York and Michigan.

Examples. — Doctor Hoover Monument at Chambersburg and McCormack Monument at Pittsburg, Pa.; W. A. Harder Monument, Hudson, N. Y.

Quincy. This is a hornblende-pyroxene granite.[1] The color is medium gray or bluish or greenish or purplish gray, to a very dark bluish gray, and dotted all over with black-appearing spots. The texture is medium to coarse, but even-grained.

That which is used for monumental purposes goes under the names of "medium dark" and "extra dark." The "light" Quincy granite, which is of medium gray color, is considered second grade and sells for rock face and hammered work.

Other and cheaper varieties suitable only for building purposes are the "extra light" (pea green), the pink and the greenish brown.

Quincy granite is noted for its high and durable polish, and one quarry has supplied a polished ball 6 feet 6 inches in diameter.

Examples. — Gore Hall, Harvard University, Cambridge, Mass.; Custom House, New Orleans, La.; Payne Building, Cleveland, Ohio; Polished ball of "dark" granite, 6 feet 6 inches diameter, Rock Island, Ill., cemetery; Bunker Hill Monument, Boston, Mass.; The Long Monument, Mansfield, Ohio.

Classification of Massachusetts Granites. The following classification of Massachusetts granites is given by Dale, the term granite being used in the commerical sense.

[1] Strictly speaking the minerals are riebeckite and ægirite.

ECONOMIC CLASSIFICATION OF THE COMMERCIAL GRANITES OF MASSACHUSETTS.

	Locality.	Trade name.	General color and shade.	Texture.	Petrographic name.
Constructional.	New Bedford	New Bedford	Light pinkish gray	Coarse inclining to medium, slightly gneissoid.	Biotite-muscovite granite gneiss.
	Dartmouth	Dartmouth	Very light buff gray	Medium inclining to coarse, slightly gneissoid.	do
	Fall River	Fall River pink	Medium or light pinkish gray with black spots.	Coarse or coarse inclining to medium, gneissoid.	Biotite granite gneiss.
	do	Fall River gray	Light buff gray or light gray	Medium inclining to coarse gneissoid.	do
	Fall River, Barlow St. q'y	Fall River, Barlow Street	Medium bluish gray	Medium, slightly gneissoid	do
	Rockport	Rockport gray, Bay View gray	Medium gray	Medium to coarse	Hornblende granite.
	do	Babson Farm	Somewhat dark greenish gray	do	do
	Lynnfield, Robin Rock q'y	Robin Rock green	Very dark greenish gray	Coarse	Hornblende augite granite.
	Peabody	Peabody green	Dark or very dark olive-greenish gray.	do	do
	Monson	Monson	Dark or very dark gray	Fine to very fine, elongated (unplicated) gneissic.	Biotite-quartz monzonite gneiss.
	Pelham	Pelham	Dark bluish gray	Very fine, elongated (unplicated) gneissic.	Biotite granite gneiss.
	North Acton, Harris quarry.	Acton	Light bluish gray	Fine gneissic	Biotite-muscovite-quartz monzonite gneiss.
	North Acton, McCarthy quarry.	Acton, fine	Medium bluish gray	Fine to very fine, obscurely gneissic.	do
	Groton, Rafferty quarry.	Groton	Light to medium gray	Medium inclining to coarse, slightly porphyritic gneissic.	Muscovite-biotite granite gneiss.
	Groton, Shaker quarry	do	Medium bluish gray	Medium inclining to fine, slightly porphyritic gneissic.	do
	Westford, Oak Hill quarries	Westford, Oak Hill	Very light or very light, slightly bluish gray	Medium, slightly porphyritic gneissic.	do
	Westford, Snake Meadow Hill quarries.	Graniteville	Very light gray or medium gray	Medium inclining to fine, slightly porphyritic gneissic.	Muscovite-biotite-quartz monzonite gneiss.
	West Townsend	West Townsend white	Light, faintly buff gray	Medium inclining to fine	Biotite-quartz monzonite
	Quincy	Quincy extra light	Light pea-greenish gray	Medium to coarse	Riebeckite-ægirite granite.
	Wrentham, High Rock	Wrentham	Light gray	Medium inclining to coarse	Hornblende granite.
	Brockton, Brockton Heights quarry.	Brockton pink	Light greenish gray with large pink spots.	Medium with large porphyritic feldspars.	Biotite- (or augite-) hornblende granite.
	Hingham	Hingham seam face	Light, lightly greenish gray, seam faces light to medium brown	Fine, slightly porphyritic	Aplite.
	Fitchburg, Rollstone Hill	Pitchburg	Light to medium bluish gray	Medium gneissic	Muscovite-biotite granite gneiss.
	Leominster	Leominster	Dark to very dark bluish gray	Very fine	Mica diorite.
	Milford	Milford pink	Light to medium pinkish or pinkish-greenish gray.	Medium to coarse, slightly gneissoid.	Biotite granite gneiss.
	Uxbridge	Uxbridge	Light to medium gray	Medium porphyritic, elongated gneissic.	do

ECONOMIC CLASSIFICATION OF THE COMMERCIAL GRANITES OF MASSACHUSETTS (Continued).

	Locality.	Trade name.	General color and shade.	Texture.	Petrographic name.
Monumental.	Becket	Chester dark and light	Medium bluish gray and medium dark bluish gray.	Fine, with traces of gneissic texture.	Muscovite-biotite granite.
	West Townsend	West Townsend white	Light, faintly buff gray	Medium inclining to fine	Biotite-quartz monzonite.
	do	West Townsend red	Light to medium pinkish gray	do	do
	Quincy	Quincy dark, Quincy extra dark.	Dark gray (or bluish, greenish, purplish) to very dark bluish or purplish gray.	Medium to coarse	Riebeckite-ægirite granite.
	Leominster	Leominster	Dark to very dark bluish gray	Very fine	Mica diorite.
Polish.	Rockport	Rockport and Bay View gray.	Medium gray	Medium to coarse	Hornblende granite.
	do	Bay View and Rockport green.	Olive green	do	do
	Rockport, prospect	Bay View dark	Dark brownish gray	do	Riebeckite-ægirite-biotite granite.
	Rockport	Pigeon Cove porphyry	Black ground with large medium gray spots.	Fine matrix and large porphyritic crystals.	Diabase porphyry.
	Peabody	Peabody green	Dark or very dark olive-greenish gray.	Coarse	Hornblende-augite granite.
	Quincy	Quincy dark and extra dark.	Dark gray (or bluish, greenish, purplish) to very dark bluish or purplish gray.	Medium to coarse	Riebeckite-ægirite granite.
	do	Quincy gold-leaf	Medium bluish gray with yellow-brown spots.	do	Riebeckite-ægirite granite with granulated quartz and limonite.
Curbing and trimming.	Monson	Monson	Dark or very dark gray	Fine, to very fine, elongated, gneissic.	Biotite-quartz monzonite gneiss.
	Pelham	Pelham	Dark bluish gray	Very fine, elongated, gneissic	Biotite granite gneiss.
	Groton, Rafferty quarry.	Groton	Light to medium gray	Medium inclining to coarse, slightly porphyritic gneissic.	Muscovite-biotite granite gneiss.
	Groton, Shaker quarry	do	Medium bluish gray	Medium inclining to fine, slightly porphyritic gneissic.	do
	Westford, Oak Hill quarries.	Westford, Oak Hill	Very light or very light, slightly bluish gray.	Medium, slightly porphyritic gneissic.	do
	Westford, Snake Meadow Hill quarries.	Westford, Graniteville	Very light gray or medium gray	Medium inclining to fine, slightly porphyritic gneissic.	Muscovite-biotite-quartz monzonite gneiss.
	Pitchburg, Rollstone Hill.	Pitchburg	Light to medium bluish gray	Medium gneissic	Muscovite-biotite granite gneiss.

RHODE ISLAND.

Westerly. An important granite industry centers at this town and the neighboring one of Niantic. The "Westerly white statuary" is a quartz monzonite of more or less pinkish or buff medium gray color, and fine even-grained texture. The "Blue Westerly" is a quartz monzonite of more or less bluish, medium gray color, with fine black particles and of fine even-grained texture. "Red Westerly" is a biotite granite of reddish gray color, speckled with black, and of even-grained, medium, inclining to coarse texture.

The so-called "white" and the "blue" are strictly monumental granites, the former, especially, lending itself to the most delicate carvings. It takes a high polish and gives good contrast.

The blue is about 50 per cent coarser than white and polishes not quite as well but gives just as good contrast.

The red is used for structural work only.

Examples. — White Westerly: National Monument, Gettysburg, Pa.; Antietam Monument, Md.; J. G. Fair Mausoleum, San Francisco. Examples of "Blue Westerly": Mutual Insurance Building, Hartford, and building of same Company in Philadelphia. Examples of "Red Westerly": Washington Life Insurance; American Tract Society and Travelers' Insurance Company buildings, New York City.

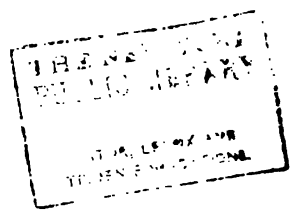
Dale makes the following classification of the chief commercial granites of Rhode Island.

	Locality	Trade name	Color	Texture
Constructional	Westerly, R. I.	Red Westerly	Reddish gray	Medium to coarse.
Monumental	Westerly, R. I.	Blue Westerly	Blue medium gray.	Fine.
	Westerly, R. I.	White and pink Westerly.	Pink or buff medium gray.	Extremely fine.
Inscriptional	Westerly, R. I.	Blue Westerly	Blue medium gray.	Fine.
	Westerly, R. I.	White and pink Westerly.	Pinkish or buff medium gray.	Extremely fine.
Statuary	Westerly, R. I.	Westerly white statuary.	Buff medium gray.	Extremely fine.

CONNECTICUT.

The granites quarried in Connecticut are practically all granite-gneiss. Some of these are of the same mineral composition as a normal granite, while others are to be classed as quartz monzonite or mica-diorite gneisses.

PLATE XXVI.— Battle Monument, West Point, N. Y. Polished shaft of Branford granite, 41 feet 6 inches long and 6 feet in diameter. (Photo loaned by Norcross Bros.)



Branford Township. This includes the well-known Stony Creek granite gneiss, and is defined as a biotite granite gneiss of medium reddish gray color, variable medium to coarse texture and gneissoid structure. The product is widely used for buildings, bridges and monuments. It takes an excellent polish.

Examples. — South Terminal Station, Boston; Bessemer Building, Pittsburg, Pa.; Newberry Library, Chicago; polished column 41 feet by 6 feet 2 inches at base) of Battle Monument, West Point; obelisk 45 feet long at Locks Park, Sault Ste. Marie, American side; Erie County Savings Bank, Buffalo, N. Y. The Hoadley Neck quarries have supplied stone for pedestals of Statue of Liberty, New York Harbor, and of General Anderson Monument, Fort Sumter, S. C.

Greenwich. The Greenwich blue-black granite is a mica diorite gneiss of dark bluish gray color, being darker even than the Quincy extra dark, and coarsely porphyritic gneissose texture. The rock is very tough and gives a brilliant surface; but the effect is different, depending on whether the grain face or hardway face is exposed.

The chief use of this stone is for buildings and massive structures.

Examples. — Fort Schuyler on Throgs Neck, Long Island Sound; Episcopal Church, Port Washington, Long Island; Catholic Cathedral, Green Avenue, Brooklyn, N. Y.

Waterford Township. A quartz-monzonite, known as "Connecticut white" granite, is quarried south of Waterford Station. This rock is of medium buff gray shade, and fine, even-grained texture, and is a fine-grained monumental and inscriptional granite, without contrasts. It is finer than the Millstone granite and of lighter shade, but only about half as fine as the "Blue Westerly." It takes a high polish.

Examples. — Soldiers' Monument, Whitinsville, Mass.; Dudley Celtic Cross, Woodlawn Cemetery, N. Y.; Hoy Mausoleum, Mount Moriah Cemetery, Philadelphia; City Deposit Bank, Pittsburg; Basement of Clark residence, Riverside Drive, New York City.

Millstone. The stone from this locality is a quartz monzonite, between medium and dark gray smoke-colored, and even-grained granitic, fine texture. It is a brilliant stone for inscriptional and monumental purposes and takes a high polish. It hammers and cuts medium gray and thus affords an excellent contrast

between this and a polished surface. The texture is about one-third as fine as that of the coarser "Blue Westerly" granite.

Examples. — Saratoga Monument, interior entrance, and all but upper 10 feet of exterior; base, pedestal and cap of P. T. Barnum Monument, Bridgeport; George W. Childs mausoleum, Philadelphia.

Groton. The several quarries at this locality yield a quartz-monzonite, of fine, granitic texture, and greenish color of slightly varying shade. It is a monumental granite, somewhat closely related to Blue Westerly, but about half as fine in texture. The polish between the cut and polished face is marked, a characteristic of all monzonites.

Examples. — William Ledyard Monument, Ledyard Cemetery, Groton; Edward Newman Obelisk, Woodlawn Cemetery, New York; Rev. Byron A. Woods Sarcophagus, Forest Hills Cemetery, Philadelphia; Charles Tyler Statue, Druid Hill Ridge Cemetery, Baltimore; Beckwith and Rogers monuments, Cedar Grove Cemetery, New London.

Among the other important quarries in Connecticut are those of the Glastonbury gneiss and Sterling granite gneiss, both used for curbing and trimming.

A list of all the Connecticut quarries by Dale and Gregory and the kind of stone which they produce is given in summarized form below.

Class.	Locality.	Trade name or quarry.	General color or shade.	Texture.	Scientific name.
Constructional.	Pawcatuck, Stonington	Red Westerly	Medium reddish gray	Medium inclining to coarse granitic.	Biotite-granite.
	Stony Creek, Branford	Branford red; Stony Creek red.	do	Medium to coarse, gneissoid. Variable.	Biotite granite gneiss.
	Hoadly Point, Branford	Hoadly Neck, West quarry.	Medium dark reddish gray	Coarse to very coarse, gneissose banded, porphyritic.	Biotite granite gneiss.
	Hoadly Point, Branford	Hoadly Neck, East quarry.	Medium reddish gray	Medium inclining to fine, gneissose.	do
	Leete Island Station, Guilford.	Leete Island quarry	do	Medium, obscurely gneissose	do
	Bristol, Bristol	Dunn quarry	Light inclining to medium bluish gray.	Fine, gneissose banded	Quartz monzonite gneiss (biotite).
	Greenwich	Greenwich blue-black	Extremely dark bluish gray	Coarse, gneissose, porphyritic	Mica-diorite gneiss.
	Benvenue, Middletown	Benvenue	Dark bluish gray	Fine gneissose porphyritic	Biotite-hornblende granite gneiss.
	Selden Neck, Lyme		Medium inclining to dark reddish gray streaked with black.	Fine gneissose, with lenses and laminæ of black silicate.	Hornblende-biotite granite gneiss.
	Norfolk	Crissey quarry	Medium very slightly greenish gray.	Fine, obscurely gneissose	Biotite-muscovite granite gneiss.
	Mine Hill, Roxbury	Rockside quarry	Medium bluish gray	Fine, very gneissose.	Muscovite-biotite granite gneiss.
	Crouch Farm, Broad Street Extension, Groton.	McIntosh quarry	Medium reddish gray	Fine, gneissose banded	Biotite granite gneiss, banded.
	Torrington	Costello quarry	Medium faintly buff gray	Fine, very gneissose	Muscovite-biotite granite gneiss.
	do	Michiel quarry	Medium inclining to dark bluish gray with much mica on foliation face.	Medium, very gneissose	do
Monumental.	Millstone Point, Waterford	Millstone quarry	Medium dark gray, smoke colored	Fine granitic (particles average 0.0354 inch).	Quartz monzonite (biotite).
	Waterford quarry, Waterford.	Connecticut white	Medium buff gray	Fine granitic (particles average 0.0206 inch).	do
	Durfy Hill, Waterford	Somers quarry	Medium inclining to dark buff gray.	Fine, granitic	do
	Groton	Salter quarry	Medium slightly greenish gray	Fine granitic (particles average 0.0235 inch).	do

Class.	Locality.	Trade name or quarry.	General color and shade.	Texture.	Scientific name.
Monumental.	Center Groton	Eckerlein quarry	Medium inclining to dark greenish gray.	Fine, granitic (particles average 0.0235 inch).	Quartz monzonite (biotite).
	do	Kopp quarry	Medium faintly green gray	Fine to very fine granitic	do
	Near Anguilla Creek, Stonington.	New Anguilla	Medium slightly bluish gray	Fine granitic	do
	Mystic, Groton	McGaughey quarry	Medium inclining to dark faintly greenish gray.	do	do
	Niantic, East Lyme	Golden Pink	Medium pinkish gray	Fine granitic (particles average 0.0275 inch).	do
	Reynolds Bridge, Thomaston.	Plymouth quarry	Medium bluish gray	Fine granitic	Quartz monzonite (biotite-muscovite).
	Lyme Village, Old Lyme	MacCurdy quarry	Medium pinkish reddish gray, spotted with black.	Very coarse, porphyritic	Pegmatite (biotite granite).
Inscriptional.	Millstone Point, Waterford.	Millstone quarry	Medium dark gray, smoke colored.	Fine, granitic (particles average 0.0354 inch).	Quartz monzonite (biotite).
	Waterford quarry, Waterford.	Connecticut white	Medium buff gray	Fine granitic (particles average 0.0206 inch).	do
	Groton	Salter quarry	Medium slightly greenish gray.	Fine granitic (particles average 0.0235 inch).	do
	Center Groton	Eckerlein quarry	Medium inclining to dark greenish gray.	do	do
	do	Kopp quarry	Medium faintly greenish gray	Fine to very fine, granitic	do
	Near Anguilla Creek, Stonington.	New Anguilla	Medium slightly bluish gray	Fine granitic	do
	Niantic, East Lyme	Golden Pink	Medium pinkish gray	do	do
Curbing and trimming.	Birch Mountain, Glastonbury.	Corbin, Brooks and Slater quarries.	Medium gray	Fine, gneissose, porphyritic	Biotite, granite, gneiss.
	Eight-mile Hill, Glastonbury.	Belden and Curtis quarries.	Medium buff gray	Fine gneissose	do
	Birch Mountain, Bolton	Peterson quarry	Medium slightly bluish gray, black streaks on foliation.	Medium, gneissose, porphyritic	do
	Eight-mile Hill, Glastonbury.	Danielson quarry	Dark to medium brownish gray.	Fine, gneissose, porphyritic	do
	Buckingham, Glastonbury.	Carline quarry	Medium, inclining to dark gray	do	do
	Near Oneco, Sterling	Marriott and Oneco quarries.	Medium, inclining to dark bluish gray.	do	do

Class.	Locality.	Trade name or quarry.	General color or shade.	Texture.	Scientific name.
Curbing and trimming.	Near Cornwall village, Cornwall.	Benedict quarry	Bright bluish gray	Medium fine, quite gneissose	Biotite, muscovite granite gneiss.
	Torrington	Michiel quarry	Medium inclining to dark bluish gray.	Medium, very gneissose	do
	East Litchfield	Mascetti quarry	Medium inclining to light bluish gray.	Fine, very gneissose	do
	Mine Hill, Roxbury	Rockside quarry	Medium bluish gray, much mica on foliation face.	do	do
	Seymour	Holbrook quarry	Medium quite bluish gray, much mica on foliation face.	Fine, gneissose	do
	Ansonia	Potter quarry	do	do	do
	Trumbull Road, Bridgeport.	Burlison quarry	do	do	do
	Norwalk	Hall quarry	Light warm gray, much mica on foliation face.	Medium fine, very gneissose	do
	Flat Rock, Waterford	Flat Rock quarry	Dark inclining to medium very faintly purplish gray.	Medium gneissose	Ægirite granite gneiss.
	do	do	Medium inclining to dark pinkish gray.	Fine gneissose	do
	Waterford	Goos quarry	Medium buff gray	Fine inclining to medium gneissose.	do
	Bolles Hill, Waterford	Scott & Richards quarries.	Medium pinkish purplish gray	Very fine, gneissose	do
Paving.	Near Sterling Station, Sterling.	Bennett boulders	Light pinkish gray, black streaks on foliation face.	Fine gneissose	Biotite granite gneiss.
Miscellaneous.	Sachem Head, Guilford	Breakwater granite	Medium more or less pinkish gray.	Very variable	do
	Masons Island, Stonington.	do	Banded light and gray	Fine granitic, with flowing bands and pegmatite lenses.	Quartz monzonite gneiss.
	Bridgeport Jail	Road and concrete	Dark bluish gray	Fine, gneissose, banded	Biotite granite gneiss.
	Town Hill, Danbury	Collins quarry, road granite.	Medium inclining to dark bluish gray.	Very fine gneissose	do
	Torrington	Borough quarry, road granite.	Dark gray with fine black bands.	Very fine to fine, gneissose, banded.	do

Market Prices of Granites. Dale gives the following prices, f.o.b. per cubic foot in rough, of some New England granites, they being the ones for 1906.

Milford, Mass., pink, in blocks up to 10 tons, $0.60 to $0.70. Foundation and bridge rubble work, $0.25.

Quincy, light, for bases and hammered work, ordinary sizes, $0.50 to $0.85. Extra light, for bridge work, without reference to size, $0.35.

Rockport, gray, ordinary sizes (3 to 15 feet long, 1½ to 4 feet wide, and 1½ to 3 feet high), best quality, $0.50.

Concord, blocks under 9 feet square in base, $0.60.

Redstone, N. H., red, ordinary sizes, $0.40 to $0.50.

Milford, N. H., dimension stone in blocks up to 100 cubic feet, $0.40.

Westerly, red, ordinary sizes, $0.60.

Quincy, medium, in blocks up to 40 cubic feet, $1 to $1.10; 40 to 55 cubic feet, $1.15. Dark, in blocks up to 40 cubic feet, $1.30 to $1.35; 40 to 55 cubic feet, $1.40. Extra dark, in blocks up to 40 cubic feet, $1.60.

Becket (Chester), in blocks up to 40 to 55 cubic feet, $1.30 to $1.40.

Redstone, N. H., green, ordinary sizes, $0.65 to $0.75.

Milford, N. H., in blocks up to 10 cubic feet, $0.75 to $1.25, averaging $0.84.

Westerly, blue, in blocks up to 10 cubic feet, $1.10 to $1.15. Up to 50 to 60 cubic feet, $2.60 to $2.75. White and pink statuary, in blocks up to 10 cubic feet, $1.10 to $1.25. Up to 50 to 60 cubic feet, $2.70 to $3.25. When the Milford, Mass., pink is ordered finished for ornamental work the following prices prevail: Rock-faced ashlar building work, $1.50. Cut building work, $3.50. Polished building work, $6. Cut monumental work, $7. Polished monumental work, $10.

Niantic, Conn., "Golden Pink," $1.25 to $2.25, from 5 to 30 cubic feet.

Dale[1] also quotes the following prices for Connecticut granites, the price unless otherwise specified being f.o.b. cars, per cubic foot, ordinary sizes, in the rough.

Constructional Granites. Stony Creek, "Branford Red," $0.75 for dimension stock, $0.53 for random. Hoadly Neck, $0.70. Greenwich (blue-black), $0.45, boat, for dimension stock; $2.75, boat, per long ton, for large random ashlar; $3.75, boat, per long ton, for small random ashlar; $1.75, boat, per long ton, for rubble. "Millstone Granite," for building, in pieces up to 30 cubic feet, averages about $0.40, f.o.b. quarries.

Monumental Granites. Waterford, "Connecticut White," $1.20 to $1.80, and "Millstone Granite," $1.25, cars or boat, from 1 to 30 cubic feet. Niantic, "Golden Pink," $1.25 to $2.25, from 5 to 30 cubic feet.

Curbing and Trimming Granites. Oneco (Marriott), $0.50; Sterling (Bennett), $0.35; Glastonbury (Belden), curbing, $0.45 per running foot at quarry, with cartage of 10 miles of rail. Seymour (Holbrook), $0.40 per running foot, 18 inches deep and four inches wide. Roxbury (Mine Hill), $0.30 to $0.40; Waterford (Flat Rock), $0.45, delivered in New London.

[1] U. S. Geol. Surv., Bull. 484, p. 127, 1911.

Miscellaneous. Guilford (Sachem Head) breakwater granite $0.999 per long ton dumped at breakwater, 12 miles from quarry, minimum weight of blocks 500 pounds. Greenwich riprap, per long ton, boat, $1.25.

NEW YORK.

This state is of little importance as a granite producer, and the occurrences are confined to the borders of the Adirondack Mountain region, including Jefferson County, and to southeastern New York. Among the causes assigned for the lack of development of the New York granites are, less favorable transportation facilities, lack of name and irregularity of deposits.

Along the St. Lawrence River a medium-grained pink granite of ornamental character and capable of good polish has been worked at Picton.

Examples. — New wing, American Museum of Natural History, New York City; First National Bank, Clayton, N. Y.

A deep red, coarsely crystalline granite, capable of taking a high polish, has been quarried on Grindstone Island, Jefferson County. It is of great beauty and ornamental value.

Another good stone occurs near Ausable Forks. This rock is of a sombre green color, takes a handsome polish and is well adapted for monumental and building work.

The coarse-grained granite, and the gray gneisses of Westchester and Putnam counties have been quarried locally. A granite occurring near Peekskill, and known as Mohegan granite, shows a yellowish tint. It has been used in the construction of St. John the Divine Cathedral in New York City.

NEW JERSEY.

Gneisses and granites are found in the Highland area of the state. This belt is from 10 to 20 miles wide, and Jenny Jump Mountain near Belvidere and Pochuck Mountain near Franklin Furnace are its northwestern outposts.

The rocks of the Highlands are chiefly light colored aggregates of feldspar and quartz which are to be classed as gneisses or granite gneisses.

The following occurrences may be mentioned.

Pompton Pink Granite. A coarse-grained pink granite, with yellowish green mottlings from the region around Pompton. It may contain gneiss inclusions. The texture is variable, varying from medium fine to very coarse grained, and there is a corresponding variation in proportions of pink, white and green colors. Some dark brown mica is present.

Examples. — St. Paul's Church at Paterson, N. J.

Dover Light Gray Granite Gneiss. This is light gray to greenish in color, medium-grained texture, and contains feldspar, quartz and greenish black hornblende in variable proportions.

Examples. — First M. E. Church, Dover.

Cranberry Lake White Granite Gneiss. A fine-grained white to very light gray granite, sprinkled with small pink garnets. Gneissic structure scarcely noticeable. A gray granite gneiss is also obtained here.

German Valley Gray Granite. A medium-grained rock with orthoclase, plagioclase, quartz, and scattered dark green hornblende. It may also be well adapted to monumental work.

Examples. — Brainerd Hall, Lafayette College, and Blair's Hall, College Hill, Easton, Pa.; Carnegie Bridge, Princeton, N. J.

Trap Rock. Several belts in northeastern New Jersey. Its main use is for foundations and concrete. The sombre color is against its extensive use.

Coarse-grained granitic types, as those found in Rocky Hill, Sourland Mountain and part of the Palisades, could be used for building.

MARYLAND.

The granites and gneisses of Maryland are all found within the Piedmont plateau province, and while granite has been developed in about fifteen areas, there are but five of importance, viz., Port Deposit, Frenchtown, Ellicott City, Woodstock and Guilford.

Mineralogically the Maryland granites can be divided into three groups, as follows:

1. Biotite granite; Port Deposit, Frenchtown, Woodstock, Dorsey's Run, Texas, Ellicott City, Ilchester.

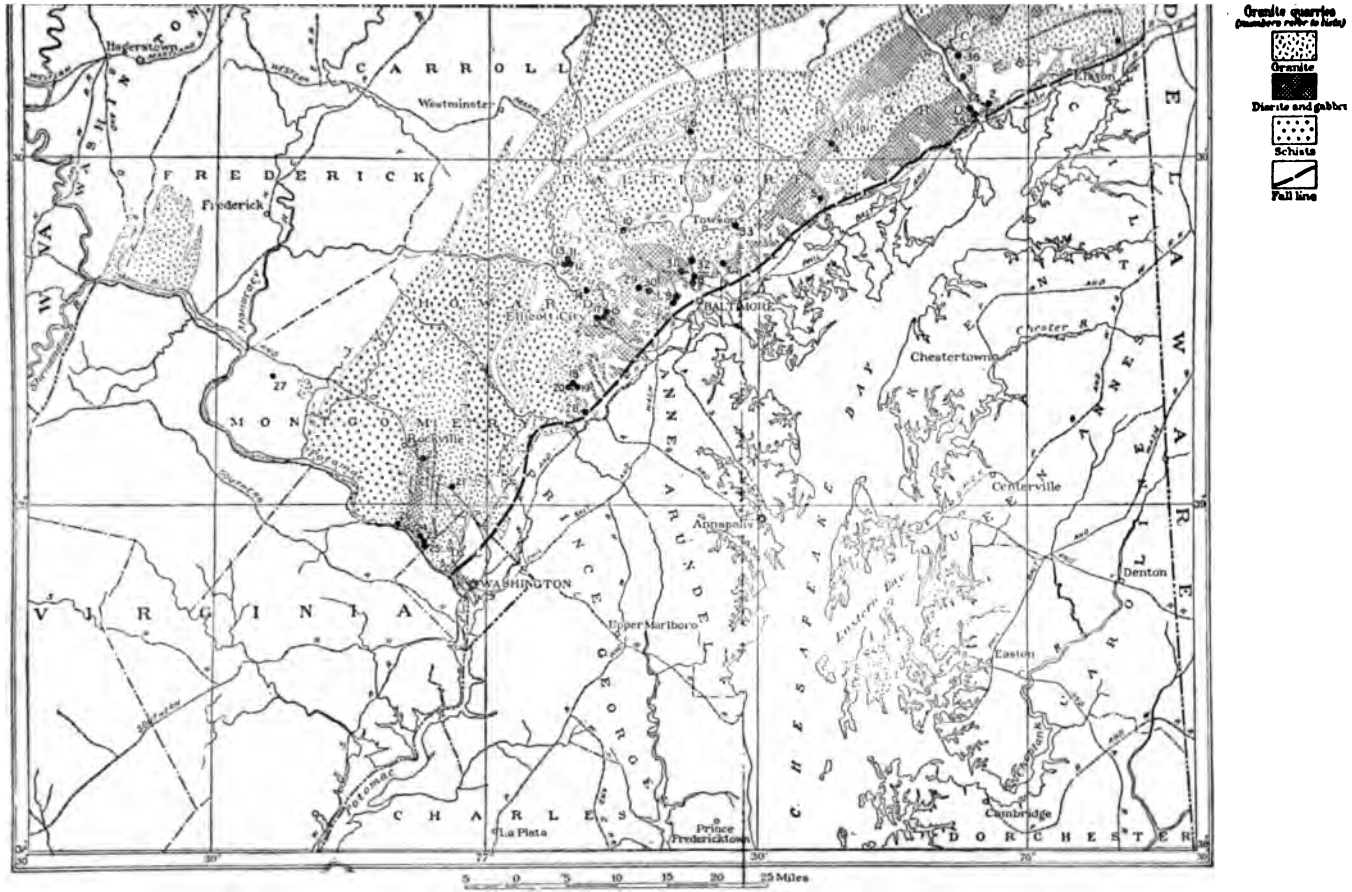


PLATE XXVII. — Map showing granite-producing areas of Maryland. (After Watson, U. S. Geol. Surv., Bull. 426.)

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2. Muscovite-biotite granite: Guilford.

3. Hornblende-biotite granite; Garrett Park. Rowlandsville.

Texturally the granites of this state are divisible into two groups, viz., granites proper and gneisses.

The more important ones are referred to below.

Granites, Port Deposit. This is the best-known Maryland granite, and is quarried on the Susquehanna River, about three miles above Havre de Grace. See Plate XXVIII.

It is a light, bluish gray granite gneiss, of medium texture, whose foliation is emphasized by the black mica scales. The stone darkens on exposure due to the accumulation of dust on the surface. It is extensively used for building in the southern states.

Examples. — Mount Royal Station, Baltimore, Md.; Maryland Penitentiary, Baltimore, Md.; Catholic University Buildings, Washington, D.C.; Girls' High School, and St. Paul's Presbyterian Church, Philadelphia, Pa.; St. Lawrence, R. C. Church, Pittsburg, Pa.; St. Patrick's Church, Erie, Pa.

Ellicott City. On the Baltimore County side the quarries yield a biotite granite of medium dark blue-gray color and medium porphyritic texture. It is somewhat foliated. On the Howard County side, the granite is a porphyritic biotite granite of dark gray color, medium grain and massive character.

Examples. — This stone has been much used around Baltimore, the cathedral in that city being constructed of it.

Guilford. This is one of the most attractive of the Maryland granites. It is a muscovite-biotite granite and varies from a coarse-grained rock of red color, through a medium-grained reddish gray to fine-grained medium gray. The last named is the most extensively quarried and is marketed chiefly in Maryland and Pennsylvania.

Woodstock. A biotite granite of medium gray color and medium grain. The slightly greater amount of biotite makes it a little darker than the Guilford and slightly coarser in texture.

The product is used chiefly for general building in both the rough and dressed states. Other uses are for monuments, paving blocks, some curbing and concreting.

Examples. — Custom House, Baltimore, Md.; Arsenal Building, Philadelphia, Pa.; Rittenhouse Building, Pittsburg, Pa.; Willard Hotel, Washington, D. C.; German Savings Bank, Baltimore, Md.

Frenchtown Area. This is a biotite granite gneiss of gray color and medium grain. It is a shade darker than the Port Deposit granite and is used chiefly for pavers.

Gneisses. The Baltimore gneiss forms several areas along the eastern slope of the Piedmont region between the Susquehanna and the Potomac rivers. Extensive quarries have been worked for many years on the north and west sides of the city of Baltimore, around Jones Falls and Gwynn Falls.

It is a quartz-feldspar-mica gneiss, of well-banded character, but variable texture and color. Bluish gray is the commonest color. The product is used chiefly in Baltimore for paving, curbing and crushed stone.

VIRGINIA.

Granites are limited to the crystalline area, which extends eastward from the Blue Ridge to the western margin of the Coastal Plain, and they comprise massive and gneissic types. The latter especially have a wide distribution over the Piedmont region and they form one of the principal types of rock.

The chief areas are: (1) the Petersburg area; (2) the Richmond area; and (3) the Fredericksburg area.

In these most important areas the granites are mixtures of quartz, feldspar and biotite, but more or less muscovite is also usually present. In addition to the principal feldspar or orthoclase, microcline and plagioclase occur in widely varying amounts.

The properties of the granites in the three important areas above mentioned are as follows:

Petersburg Area. A biotite granite of medium texture and gray color, adapted to constructional and monumental work.

Richmond Area. This is the largest producing area in the state, a number of quarries being located in immediate vicinity of Richmond and Manchester. These are biotite granites from fine to medium texture and light to dark gray color. An exceptionally beautiful type is the porphyritic granite occurring near Midlothian, thirteen miles west of Richmond.

Two grades of granite are recognized: one a fine-grained, dark blue-gray stone, extensively used as monumental stock; the other

PLATE XXVIII, Fig. 1. — Port Deposit, Maryland, gneissic granite with face cut at right angles to banding.

PLATE XXVIII, Fig. 2. — Port Deposit, Maryland, gneissic granite with face cut parallel to the banding.

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ASTOR, LENOX AND
TILDEN FOUNDATIONS

a lighter gray rock, well adapted to building purposes. The former takes high polish and gives strong contrast between polished and hammered surface.

Examples. — State, War and Navy Building, Washington, D. C.; St. Andrews Church and Union Theological Seminary, Richmond, Va.

Fredericksburg Area. Two types of granite are obtainable (1) a very light gray medium-textured, muscovite granite, and, (2) a dark blue-gray, very fine textured biotite granite, identical with that quarried in the Richmond area and used for monumental stock.

Other Localities. Gneisses have been quarried in the region around Lynchburg and used locally. They are also worked at a few other localities.

A yellow, green and pink epidote granite, known as unakite, is found at two localities, viz., Milams Gap in the Blue Ridge near Luray and Troutdale, Grayson County. It is moderately coarse, but shows an irregular crystallization of red feldspar, quartz and green epidote.

Trap rock or diabase is rather widely distributed over parts of the Blue Ridge and the crystalline area in Virginia, but only a few quarries have been opened in it, the principal ones being in Loudoun, Fauquier and Culpepper counties. The stone has been used for paving purposes and bridge abutments only.

NORTH CAROLINA.

Granites are distributed over about one-half the total area of the State, but quarries have been operated at only a few localities.

The granites and gneisses occur in the coastal plain, the Piedmont plateau and the Appalachian Mountains district, but the larger part of the granites are comprised within the limits of the Piedmont plateau region.

The North Carolina granites show a mineralogical resemblance to those of the other states in the southern Appalachian region. That is to say, they are mixtures of feldspars (plagioclase usually in excess), and quartz, with biotite as the third essential mineral in the most important areas. They are characterized by a

strong development of vertical joints, the most noteworthy exception being the granite of Mount Airy.

Watson makes the following divisions on a mineralogic basis:

1. Biotite granite, with or without muscovite, and including most of the areas of the state, such as Mount Airy, Dunns Mountain, and Greystone.
2. Hornblende biotite granite, including the granites of northern and southern Mecklenburg County.
3. Muscovite granite, with or without biotite, as Warren Plains in Warren County.
4. Epidote granite, from Madison County.

Knots are entirely absent in some quarries and occur only here and there in others, but in a few they are so abundant as to disfigure the granites for some of the higher grades of work.

Most of the quarries show pegmatite dikes, and in some these are so abundant that dimension stone is difficult to obtain. This is especially true of the Raleigh City quarries, where hardly a block entirely free from quartz feldspar dikes can be extracted.

The bulk of the North Carolina granites are of even-granular character and range from massive to partly schistose rocks of fine to medium texture, rarely coarse. The color is pink to gray, but prevailing light to medium dark gray.

The North Carolina granites may be grouped on a textural basis as even-granular granites and porphyritic granites.

Even-granular Granites. These have a wide distribution and include the bulk of the North Carolina granites. Those in the several topographic provinces may be briefly referred to.

Coastal Plain. Granites are found at several localities, especially in Wilson, Edgecomb and Nash counties, east of Raleigh. The openings are small and made for local use only.

Piedmont Plateau Region. This is commercially the most important area in North Carolina and contains several granite belts approximately parallel to one another. The granites are usually biotite bearing, with additional hornblende in several of the areas, but muscovite is rare. They are usually some shade of gray, but occasionally pink is the characteristic color.

The stone is often of good quality, readily accessible and easily worked. Some of the more important areas are referred to below.

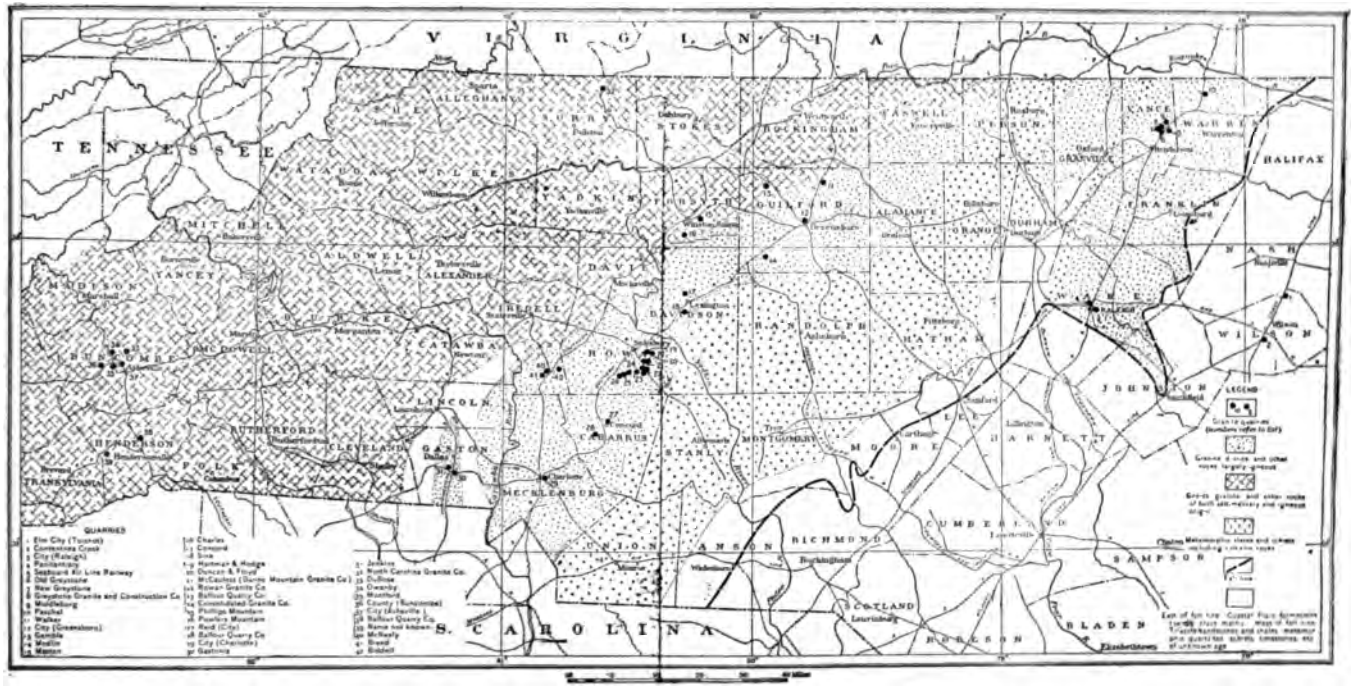

Fig. 3. — Map showing granite-producing areas of North Carolina.

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Greystone. This is one of the best-known North Carolina granites and has been worked for a long time. It has been used mostly for street purposes, in the form of blocks for coping and bridges, and to a less extent as a building stone. The stone is a biotite granite of gray to pinkish gray color, fine to medium grain and schistose structure.

Raleigh. This is a biotite granite of medium gray color and even, fine grain, with a somewhat schistose structure. It is used chiefly for common building and curbing.

Wise. A muscovite-biotite granite of medium light gray color, medium grain and massive character. Is quarried for general dimension work.

Rowan County. One of the most important granite areas in the state lies near Salisbury, Rowan County, where, beginning about four miles east of Salisbury, it extends southward for more than twelve miles. The stone has been widely used in North Carolina and adjoining states. Both a light gray nearly white biotite granite and a pink one of uniform color and texture are quarried.

Both kinds occur at Dunn's Mountain, four miles east of Salisbury, and, while there is no difference in durability, the pink is more desirable for certain classes of high-grade work.

Some of the pink granite is of a beautiful color and takes a high polish.

Examples. — Catholic University, Washington, D. C.; New Municipal Court Building, Washington, D. C. The pink granite is in much demand in Chicago and other northern and central cities for monumental stock.

Mount Airy. The stone quarried here is a very light gray biotite granite of medium texture, and contains no visible injurious minerals. It is excellently adapted to general constructional work, but not good for monumental work where contrast between hammered and polished surface is desired.

Examples. — Dry dock at Newport News, Va.; Union Trust Building, Washington, D. C.; third story of New National Museum Building, Washington, D. C.

Porphyritic Granites. These occur at many points in the same regions as the even-granular ones, but they are not regularly quarried.

An exceedingly interesting and beautiful rock is a quartz porphyry which occurs near Charlotte, Mecklenburg County. It is a dense, hard, tough, compact, finely crystalline rock of nearly white color, with faint greenish tinge in places. The stone is penetrated by long parallel streaks or pencils of black color. When broken at right angles to the streaks the surface is dotted with rounded irregular spots, but when cut along the streaks they show a curious branching pattern. (Plate XXIX.)

The rock takes an excellent polish and could be used with splendid effect for inlaid work.

Miscellaneous Rocks. West of Lexington, Davis County, there occurs an orbicular gabbro-diorite. It is of dark color, with a greenish cast, and shows a curious mottled appearance due to numerous dark-green areas of hornblende, ranging from an eighth inch to several inches in diameter, set close together, and the interstices filled with white feldspar. The effect produced on a polished surface of the stone is at once unique and beautiful. It seems to be a neglected ornamental stone. (Plate XXIX.)

SOUTH CAROLINA.

The granitic rocks of this state occur in a roughly triangular area, lying between the fall line on the southeast, the Savannah River and Georgia on the southwest, and the North Carolina boundary on the north.

The chief producing areas are Columbia in Richland County; Lexington, Lexington County; Edgefield, Edgefield County; Winnsboro, Fairfield County; Heath Springs, Lancaster County; Beverly, Pickens County.

In common with those of the southeastern Atlantic States, the South Carolina granites vary in structure from massive to gneissose, and in texture from even granular to porphyritic.

The South Carolina granites are, with one exception, biotite granites, even granular, fine- to medium-grained (rarely coarse-grained), and usually some shade of gray.

Porphyritic ones are common, but less numerous than in Georgia and North Carolina.

PLATE XXIX, Fig. 1. — Leopardite from North Carolina. (T. L. Watson, photo.)

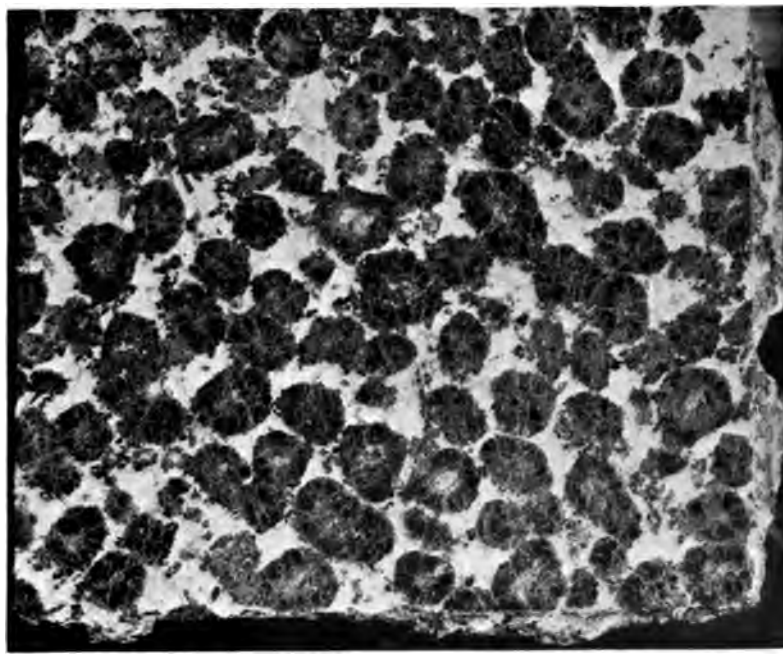

PLATE XXIX, Fig. 2. — Orbicular gabbro from North Carolina. (U. S. Geol. Surv.)

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Of the granite gneisses, those quarried by the Grenville Granite Company in Pickens County are most typical. They resemble closely the contorted biotite granite gneiss of Lithonia, Ga.

Pegmatite veins are common in some of the quarries, but are not usually large, while quartz veins are exceptional. Vertical joints are present, but horizontal joints are less commonly developed than in the granite quarries of the other southern states.

Among the best-known South Carolina granites are those of the Rion and Anderson quarries of the Winnsboro Granite Corporation.

The Rion granite is a gray stone, used chiefly for building stone, while the Anderson granite is a blue-gray used exclusively for monuments.

The working qualities of the Rion granite are excellent and it is splendidly adapted to architectural work, for which it has had an extensive sale, as indicated in the following list of prominent structures in which it has been used:

Examples. — United States Court House and Post Office Buildings, Wilmington, N. C.; Asheville, N. C.; and Opelousas, Ala. Post Offices, Charleston, S. C.; Durham, N. C.; Chillicothe, Ohio; Traverse City, Mich.; Florence, S. C., and Charlottesville, Va. Fidelity Title and Trust Company Building and Hussey Building, Pittsburg, Pa.; New Land Title and Trust Company Building, Philadelphia, Pa.; United States Custom House, Baltimore, Md.; Building No. 1, commandant's office, Navy Yard, Charleston, S. C.; Fairmount Trust Company, Fairmount, W. Va.; and Empire Bank Building, Clarksburg, W. Va.

In addition to its principal use in architectural work, the product is used for monument bases. The dry docks at Charleston, S. C., were built of this stone, 200,000 cubic feet being used.

The Anderson stone is dark blue-gray in color and fine grained. It is closely similar to dark blue-gray granites at Oglesby, Ga.; Heath Springs, S. C.; Richmond and Fredericksburg, Va.

Heath Springs. This rock is a biotite granite of uniform dark gray color and fine grain. It takes a high polish, and is adapted to high-grade monumental stock, for which it is exclusively used. The product has been shipped as far as Brooklyn, N.Y., Denver, Colo., and Portland, Ore.

Columbia. Several quarries are located near here. It is a biotite granite of gray color and fine to coarse grain, or again of

reddish gray color and medium grain, with pronounced porphyritic tendency. The product is used chiefly for rough and crushed stone.

GEORGIA.

Granites of excellent quality and some variety, well suited for general building and monumental work, have long been known in Georgia, although for many years the light gray Stone Mountain granite was the only one known beyond the limits of the state.

The granites occur in the Piedmont region which occupies the middle northern portion of the state, but while granites and granite gneisses are widely distributed throughout this area, only four counties are important producers, and of these DeKalb is the most important.

The five producing areas are as follows:

1. *Elberton-Oglesby-Lexington Area.* In the Oglesby-Lexington district we have a biotite granite of dark blue-gray color, and fine, even grain. It is fairly uniform in texture and color, works well under the hammer, and takes an excellent polish with striking contrast between cut and polished surface.

The uniformity of color and texture, fineness of grain, freedom from imperfections and blemishes, together with great strength and durability, rank it high as a monumental stone. The Elberton-Echols Mill district, although continuous with the preceding, is a biotite granite of light-gray color and medium, even-grained texture. The stone is well suited to all grades of constructional work.

2. *Lithonia-Conyers-Lawrenceville Area.* This represents one of the two principal areas of granite gneiss, the other being the Odessa-Mountville area. In the former the principal quarrying center is Lithonia. The rock is hard, firm, close textured, fine-grained biotite granite gneiss, of medium-gray color. The granite is used chiefly for paving and curbing.

3. *Fairburn-Newman-Greenville Area.* This region supplies an even-granular massive biotite granite of two varieties. One is a medium gray, fine-textured rock; the other is a dark bluish gray granite of more coarsely crystalline texture and darker color.

The stone is admirably adapted for general building and constructional work and, in places, for monumental stock.

4. *Stone Mountain Area.* Stone Mountain is an elliptical ridge of granite, 686 feet high and 7 miles in circumference, rising above the surrounding plain. The area yields a biotite-bearing muscovite granite of uniformly light gray color and moderately fine-grained but variable texture.

The stone is extensively used for general building purposes, and has been marketed in the principal towns and cities of the South and West. Its light color makes it undesirable for monumental stock.

5. *Sparta Area.* There are a number of porphyritic granites known in Georgia, but except in the Sparta area they have been very sparingly quarried, and then only to supply a strictly local demand.

The Sparta stone is a prevailingly coarse-grained, medium-gray porphyritic biotite granite, which appeared to be used chiefly for paving purposes.

ALABAMA.

The crystalline rocks of Alabama occupy a triangular area in the northeastern part of the state.

Granite of good quality occurs in considerable quantity at a few localities in the crystalline area of Alabama, but no regular quarries have been opened. Granite gneisses are also known.

WISCONSIN-MINNESOTA AREA.

Wisconsin.

The igneous rocks quarried in Wisconsin are mainly granite and rhyolite, and the purposes for which they are quarried are monumental, building and rock construction.

According to Buckley the Wisconsin quarries furnish thirteen different colored and textured granites. These include all colors from brilliant red to dark gray, and all textures from very fine-grained to coarsely porphyritic ones.

The most important ones are referred to below.

Montello. A dense fine-grained granite of red color, or sometimes a grayish red. There is no regularity in occurrence

of the two types. Black and white streaks sometimes traverse the stone and have to be avoided for monumental work. The granite takes an excellent polish, and the hammered surface is much lighter. It is a stone of exceptional beauty, and is a valuable monumental stone.

Examples. — Wisconsin Soldiers' Monument, Gettysburg, Pa.; Sarcophagi in Gen. Grant's Tomb, New York City; Wisconsin Monuments, National Park, Vicksburg, Miss.

For structural work it has been used in Herald Building, Chicago, and several private residences.

Berlin. The stone is known as quartz porphyry, but is properly a rhyolite. It is very compact, of dense and uniform texture. The color in general is grayish black, but often shows a pinkish tinge from large feldspars scattered through the ground mass. Occasional small, black streaks which mar the ordinarily uniform color occur in the rock.

Degree of polish depends on surface polished. The "run" and "head" surfaces take a very excellent finish, but the rift side does not. The polished surface is dark grayish black, and the hammered face light bluish gray.

It is a strong, durable monumental stone, and the only injurious characteristics are the occasional occurrence of incipient cracks, black streaks and veins of white quartz.

Examples. — Used in Science Hall, Madison, Wis., and Bartlett Building, Chicago, Ill. Many paving blocks are made from it.

Warren. This stone, which is quarried about twelve miles northeast of Berlin, is known as Waushara granite. The color is deep pink, but lighter than Montello, on both the hammered and polished surfaces. It takes a fine polish, but the contrast between hammered and polished surface is not extra strong, and is fine grained. It consists essentially of quartz and feldspar, these making up 90 per cent of the rock, while hornblende and muscovite are subordinate. The stone is used mainly for monumental work and paving.

Waupaca. A beautiful porphyritic granite in several colors, viz., black and pink, called gray; green and pink, called red. Pink feldspars predominate in nearly all varieties.

The rock consists mainly of large feldspars between which are disseminated small crystals of feldspar, quartz, hornblende, biotite, chlorite and epidote.

Flesh-colored feldspar contributes a reddish tinge to the rock, while the biotite and hornblende are the sources of the black color. The green color is due to epidote and chlorite.

In general, it takes excellent polish, the red taking better than gray. The hammered surface is pinkish red color, but the contrast is not very sharp. Owing to coarse feldspars, some difficulty is experienced in dressing sharp corners. It is best suited for inside work.

Examples. — Omaha Bee Building, Omaha, Neb.; Gateway to Lake View Cemetery, Minneapolis, Minn.; Wisconsin State Soldiers Monument at Chickamauga, Tenn.

Wausau. This is a medium coarse grained, reddish brown, red or gray granite, with a little biotite and hornblende, which takes a high polish and gives good contrast between the hammered and polished surface. It is used for monumental, ornamental and constructional purposes.

Example. — Marathon County Bank, Wausau.

Amberg. Fine-grained gray granite mainly for ordinary constructional work.

Example. — Chicago Historical Society, Chicago, Ill.

MINNESOTA.

The two chief granite-producing areas are near St. Cloud and Ortonville, which are located respectively 65 and 179 miles northwest and west of Minneapolis. Three kinds of granite are quarried near St. Cloud, viz., (1) a pinkish gray medium-grained stone, used in construction of the new Federal Building at St. Paul; (2) a fine-grained gray syenite, and (3) a red syenite.

The price of the St. Cloud stone in rough blocks is said to be from 75 cents to $1.25 per cubic foot.

The Ortonville granite is of dark red color and medium to coarse grained, and has been used for structural and ornamental work in both Minneapolis and St. Paul.

The Capitol at St. Paul contains several polished columns of this stone, and the exterior of the City Hall and County Court House Building at Minneapolis is faced with red Ortonville granite.

Southwestern Area.

MISSOURI.

The igneous rocks lie chiefly in the St. Francois Mountains area, and consist mainly of granite and rhyolite.

The major portion of the granite is in an area of about 110 square miles, lying west and southwest of Knob Lick, but aside from this there are a number of small areas clustered around Fredericktown, Madison County.

The granite, which is a quartz-orthoclase-biotite rock, with subordinate hornblende, varies from a light gray, through different shades of reddish pink to brownish red, but the prevailing color is some shade of red.

Much of it is of porphyritic texture, but still there is much variation from this. The Cornwall granite is very coarse, that of Graniteville a little less so, while the Knob Lick is medium grained.

The rhyolite varies from many shades of dark red and wine color, to dark brown and black. It is not popular as a building stone, for, although it takes a good polish, it is badly broken by joints.

Graniteville. The largest and most important quarries in the state are here. The stone is a red granite of pleasing red color, medium to coarse grained, and takes a good durable polish. It is, therefore, much used for constructional and monumental work.

Blocks of large size can be extracted, and columns 16 feet long and 2 feet 6 inches in diameter have been obtained.

Examples. — Merchants Bridge and Terminal Railway, and Mercantile Library, St. Louis, Mo.; Thos. Allen's Monument, polished monolith of 42 tons weight, Pittsfield, Mass.; Post Offices, St. Louis, Mo.; and Cincinnati, Ohio; Whitney National Bank, New Orleans, La.; columns on Flood Building, San Francisco.

Knob Lick. The granite of this district is of a gray to grayish red color, and finer grained than that of Graniteville. Knots

are not uncommon in it and may cause trouble. Much quarrying for paving blocks was done here in former years.

ARKANSAS.

Syenite quarries have been worked near Little Rock. That obtained on Fourche Mountain is a coarsely crystalline, dark bluish gray rock, which is strong and durable, but may be objected to by some on account of its dull color.

Example. — Pulaski County Court House, Little Rock.

OKLAHOMA.

The chief granite areas of Oklahoma are in the Wichita and Arbuckle Mountains.

Wichita Mountains. These lie in southwestern Oklahoma, and contain a number of different kinds of igneous rocks, but the granite is the most important.

It varies from a dark red to light pink and from moderately coarse to finely granular.

At Granite City, in the northwestern part of the Wichita Mountains, two types of granite have been quarried. One of these is a medium-grained, the other a fine-grained red granite.

In the coarser grained granite the hammered and polished faces do not show marked contrast. Some care has to be used in avoiding knots in quarrying.

The finer grained granite takes a smoother polish, is a dark brownish red on the polished surface, and not so brittle as the coarser grained stone.

A grayish-pink fine-grained granite is quarried near Mountain Park, and a gray fine-grained one near Cold Springs. Near this same locality a dark bluish gray, medium- to coarse-grained anorthosite has also been worked. This rock is composed almost entirely of a plagioclase feldspar known as anorthite. It takes a beautiful bluish black polish.

Arbuckle Mountains. These lie in south central Oklahoma. They contain a coarse-grained pink granite which has been quarried and used for building purposes.

TEXAS.

Granite occurs abundantly in parts of Llano and Burnet Counties, some of the stone being clean, but other portions containing included fragments of schist.

The several varieties obtainable are as follows:

1. Coarse-grained pink variety. This is most extensively quarried at Granite Mountain, Burnet County. It is a biotite granite and contains some pegmatite dikes.

Examples. — Austin Capitol, Galveston and Houston Court Houses, and Galveston Sea-wall.

2. A fine- to medium-grained gray variety. This is quite abundant, and somewhat resembles the Barre granite.

3. A fine- to medium-grained pink variety.

Cordilleran Area.

MONTANA.

Granite is found in most of the counties west of and including the Rocky Mountains, but Lewis and Clarke County is the largest producer in the state, there being several quarries near Helena.

Next to this region that at Welch's Spur near Butte is the most important.

The volcanic ash deposits found near Dillon are usually sufficiently hard to be used for building purposes, and many buildings in Dillon are constructed of it. It is not adapted for use in large buildings and has to be set with a non-staining mortar.

COLORADO.

Granites and gneisses are very abundant in the whole mountainous region except in the extreme south. Many of them are suitable for building and vary from dark gray to dark red. Building granites are found along the eastern border of the mountains and at Sahda, Texas Creek, Cotopaxi and other points within the range.

A fine-grained gray rhyolite is quarried in large quantities at Castle Rock, south of Denver, and has been extensively employed

for building in that city, but more recently it has been superseded by a similar rock of andesite nature from Del Norte.

Although volcanic rocks are abundant in this state and also the other southwestern states, they are not used to the same extent as in Mexico, where consolidated tuffs and lavas are employed, not only for constructional work, but also for ornamentation.

CALIFORNIA.

The state contains extensive areas of granite and granite-diorite, but the quarrying industry of these stones is comparatively small.

Rocklin. This stone is a light to dark-gray biotite granite, varying somewhat in texture. The stone is usually fine grained and takes a good polish.

Raymond. This is a medium fine-grained biotite granite, which sometimes carries hornblende. The color is light gray.

Examples. — New Post Office, San Francisco; three lower floors, Fairmount Hotel, San Francisco.

Riverside County. Granite is abundant in this county and has been quarried for building and ornamental purposes at Corona, Riverside and Temecula.

A small amount of gabbro is quarried at Penryn.

OREGON.

Much building stone is used in Portland, but only a small proportion comes from this vicinity. The local basalt and andesite have furnished material for a few buildings but not much now.

The black basalt, constituting the greater portion of the highland west of Portland has been used extensively for foundations. Its dark color and difficulty in dressing are the main objections to its use.

The gray basalt of Rocky Butte is being used in increasing quantity.

CHAPTER IV.

SANDSTONES.

SANDSTONES are normally composed of grains of quartz bound together by some cementing substance. Other minerals may be and often are present, at least in small quantities. These accessory minerals include feldspar, mica, iron oxide, pyrite or even tourmaline. In rare cases feldspar may form the predominating mineral, and more frequently mica may be so abundant as to attract attention (Connecticut brownstone).

Texture. Sandstones range in texture from very fine grained ones, through those of medium coarseness, to extreme cases in which the grains are quite large; so by increasing coarseness they pass into conglomerates. On the other hand, by increasing fineness and increasing clayey matter they may grade into shales.

Hardness. The hardness of a rock, as already explained, depends on the state of aggregation of the mineral grains and also upon the hardness of the grains themselves. A sandstone, therefore, although composed entirely of quartz grains, might be comparatively soft if these grains were loosely cemented.

The cementing material in sandstones may be iron oxide, silica, lime carbonate, or clay. The quality and character of the cement affects the strength, durability, workability and even color of the stone. In some sandstones more than one kind of cementing material is present.

Silica cement is the most durable, but if present in too great quantity makes the stone too hard to work. The Berea sandstone of Ohio contains a moderate amount of siliceous cement, while the Potsdam sandstone of New York is strongly cemented with the same material.

Iron oxide may also act as a strong binder of the sandstone grains, but does so to a less degree than silica, and at the same time it imparts color to the stone.

Calcium carbonate, though giving a fairly strong cement, is an undesirable one, for the reason that it is not only soft but readily dissolves in carbonated waters. It rarely produces any noticeable discoloration. It can be detected usually by the effervescence when a drop of cold dilute muriatic acid is put upon the stone. Small amounts do no special harm.

Clay as a cement possesses both advantages and disadvantages. It is not as strong as the others, and moreover serves to attract moisture to the stone; hence an excess of clay might render the sandstone liable to injury from frost. A small amount is an advantage, as it softens the stone somewhat and facilitates dressing. If present, the clay should be uniformly distributed, for its occurrence in thin seams may cause the rock to split or flake off along these.

Color. This may be due to iron compounds, clay or carbonaceous matter.

Limonite (hydrous iron oxide) colors a sandstone various shades of buff, yellow and yellow-brown. Hematite (iron oxide) may give red or red-brown tints. But if the iron is unevenly distributed a blotchy appearance is produced.

A faint bluish or greenish tint is possibly due to iron sulphide, iron carbonate, or more rarely iron silicate being present in a very finely divided condition.

Clay will often impart a grayish color to a sandstone, and at the same time a somewhat dull or earthy appearance. Carbonaceous matter may also cause gray or black coloration.

Absorption. Sandstones show a wide range of absorption. Hard, dense ones, like quartzites, will absorb under 1 per cent of their weight of water. Many absorb 2 to 3 per cent and very porous ones take up as much as 10 or 11 per cent.

Crushing Strength. The average of many tests shows a range of from 9000 to 12,000 pounds per square inch. Some well-known ones run as low as 5000 pounds per square inch, while hard sandstones and quartzites not infrequently show a crushing strength of 15,000 or even more pounds.

The following table contains some tests of sandstone from different localities.

TESTS OF SANDSTONE.

Locality.	Crushing Strength.		Transverse strength, modulus of rupture.	Absorption per cent.	Spec. grav.
	Position.	Lbs. per sq. in.			
Presque Isle, Wis.	Bed	6,244	.....	.....	.....
Presque Isle, Wis.	Edge	4,747	.....	.....	.....
Houghton, Wis.	Bed	4,549	574.6	8.89	.....
Houghton, Wis.	Edge	4,090	.....	.....	.....
Dunville, Wis.	Bed	2,502	.....	15.22	2.582
Dunville, Wis.	Edge	2,942	.....	.....	.....
Port Wing, Wis.	Bed	5,498	.....	10.33	2.649
Port Wing, Wis.	Edge	1,658	.....	.....	.....
Portland, Conn.	.....	12,580	2073	.....	2.35
E. Longmeadow, Mass.	.....	12,210	.....	.....	2.49
Potsdam, N. Y.	.....	.....	.....	2.08	2.604
Marquette, Mich.	.....	3,800	.....	5.00	2.16
Waltonville, Pa.	.....	14,753	.....	4.00	2.66
Medina, N. Y.	.....	16,031	.....	.....	.....
Kettle River, Minn.	.....	11,547	.....	.....	.....
Berea, O.	.....	11,213	.....	.....	.....
Warrensburg, Mo.	Bed	5,911	777.97	7.64	2.649
Warrensburg, Mo.	Edge	4,869	.....	.....	.....
Flagstaff, Ariz.	.....	6,309	.....	3.76	2.346
Colusa, Cal.	.....	8,880	.....	3.025	2.558
Columbus, Mont.	.....	8,500	.....	3.9	2.34
Warsaw, N. Y.	.....	19,022	.....	.....	.....
Tenino, Wash.	.....	5,750 3,270	.....	.....	.....

The following analyses are given for those who may desire them, to show the variation in composition of several sandstones used for building.

	I.	II.	III.	IV.	V.	VI.
Silica (SO_2)	70.11	84.40	89.33	76.53	76.50	90.34
Alumina (Al_2O_3)	13.49	7.49	6.05	11.37	14.75	4.35
Ferric oxide (Fe_2O_3)	4.85	3.87	1.41		6.35	1.09
Lime (CaO)	2.39	0.74	trace	9.56[1]	.....	0.95
Magnesia (MgO)	1.44	2.11	trace	0.41	.....	0.17
Potash (K_2O)	7.37	0.24	2.12	.....	.....	1.30
Soda (Na_2O)		0.56	0.59	.....	.....	0.19
Water (H_2O)		.....	.....	.....	2.00	0.61

[1] As carbonates.

I. Portland, Conn.; II. Berea, Ohio; III. Port Wing, Wis.; IV. Warrensburg, Mo.; V. Warsaw, N. Y.; VI. Hummelstown, Pa.

Weathering Qualities. Sandstones, as a rule, show good durability. Some of the softer ones may disintegrate under frost action. Those with clay seams are liable to split with continued freezing. Mica scales, if abundant along the bedding planes, are also likely to cause trouble, and this is aggravated if the stone is set on edge instead of on bed. A striking example of this is the Connecticut brownstone so extensively used in former years for fronts in many of the eastern cities. In order to get a smooth surface it was rubbed parallel with the bedding, and the stone set in the building on edge. The result is that hundreds of buildings put up more than fifteen or twenty years ago are scaling badly, and in many cases the entire front has been redressed.

Sandstones sometimes change from gray to buff or brown on exposure to the weather due to the oxidation of the iron, but this does not necessarily indicate deterioration of the stone.

Fire Resistance. Sandstones are perhaps as little affected by a heat of 1500° F. as any building stones, but are likely to spall and crack when exposed to the combined effects of fire and water. Some show a tendency to split along the bedding planes.

VARIETIES OF SANDSTONE.

The following variety names are based on difference in color, mineral composition and texture.

Arkose. A sandstone composed chiefly of feldspar grains. Some is quarried in New Jersey.

Bluestone. The name belongs properly perhaps to a flagstone much quarried in eastern New York. It is also used for bluish gray sandstones quarried at other points, as, for example, the Warsaw bluestone of western New York.

Brownstone. A term formerly applied to sandstones of brown color, obtained from the Triassic formation of the Connecticut Valley of Connecticut and Massachusetts, and in other eastern states, but since stones of other colors are found in the same formation, the term has come to have a geographic meaning and no longer refers to any specific physical character.

Calcareous Sandstone. One in which carbonate of lime forms the cementing material.

Ferruginous Sandstone. One containing considerable iron oxide in the cement.

Flagstone. A thinly bedded, argillaceous sandstone used chiefly for paving or flagging purposes.

Freestone. A sandstone which splits freely and dresses easily.

Graywacke. A hard sandstone of compact character, composed of grains of quartz, feldspar, slate and perhaps other minerals, with a clayey cement.

Quartzite. A very hard, usually very dense sandstone, which owes its hardness to pressure, or more commonly deposition of silica around the grains.

Distribution of Sandstones and Quartzites. Sandstones and quartzites are widely distributed in the United States; indeed, so much so that there are numerous small quarries opened up in many states to supply a local demand.

In a few cases, certain areas have been worked on a large scale to supply a wide extent of territory. This is true of the Connecticut brownstone, so much worked in former years, and of the Berea sandstone of Ohio, which is extensively used now in the eastern and central, and, to not a small extent, in the western states.

In view of this wide distribution of sandstone, it becomes somewhat difficult to pick out a few prominent areas.

New England States.

Sandstones are of little importance in most parts of New England.

The best known is that of the Triassic formation of Connecticut and Massachusetts, which has been widely used in former years. This is a rather fine-grained sandstone, usually of reddish brown color, moderate density, and not extra hard. It lies in horizontal beds which vary from a few inches to twenty feet in thickness (Merrill). On account of the large amount of quarry water which it contains it cannot be quarried in freezing weather; indeed, Merrill states that a temperature of 22° F. is sufficient to freeze and burst blocks of the freshly quarried material; but a

week or ten days of good drying weather is considered enough to protect the stone against frost.

The fact that the stone splits under frost action when set on edge instead of on bed has somewhat injured its reputation.

A brick-red variety of fine uniform grain is quarried at Kibbe, and East Longmeadow, Mass.

The Connecticut brownstone has been extensively used in the eastern cities for constructional work, and especially as veneer blocks over brick for the fronts of buildings. It has also been much employed in former years for headstones in cemeteries. The Kibbe rock has found similar applications.

Examples. — Academy of Design, Brooklyn, N. Y.; Wesleyan University Buildings, Middletown, Conn.; Holy Trinity Episcopal Church, New York City; Court House and Post Office, Rochester, N. Y.; lower stories of Waldorf-Astoria Hotel, New York City; Marshall-Field Building, Chicago, Ill. (Kibbe sandstone above basement); Trinity Church, Boston, Mass.; Library and Stock Building, Princeton University, Princeton, N. J.; numerous private residences in Boston, New York, Philadelphia and other eastern cities.

Eastern Atlantic States.

These contain an abundance of sandstone suitable for building purposes.

They may be briefly summarized as follows:

NEW YORK.

Medina Sandstone. A moderately fine-grained sandstone of light gray (called white) or red color and quarried chiefly between Rochester and Lockport. The red is used chiefly for building purposes, and has a bright color. The gray may be used with it, but its main use is for paving blocks.

Both types are stones of good durability and low absorption.

Potsdam Sandstone. This is essentially a quartzite, usually very hard, dense, moderately fine-grained, and of red or reddish brown color. It is perhaps less used now than formerly. Its main occurrence is in northwestern New York, but it is also found in the east along Lake Champlain.

Examples. — Many buildings in Potsdam, N. Y.; All Saints Cathedral in Albany, N.Y.; parts of the Dominion Houses of Parliament, Ottawa, Canada.

Warsaw Bluestone. A fine-grained bluish gray sandstone of earthy appearance, much used for constructional work, but especially for trimmings in many of the eastern cities.

Examples. — University Avenue M. E. Church, Syracuse, N. Y.; Genesee Street Baptist Church, Rochester, N. Y.

Hudson River Bluestone. The typical bluestone is a fine-grained, compact, tough sandstone, of blue-gray color, which breaks up readily into slabs a few inches thick, and sometimes of large size. On this account it has been extensively used for flagging, curbs, sills, steps, etc. It is quarried chiefly in Albany, Green and Ulster Counties. Some slabs of large size have been extracted.

NEW JERSEY.

Sandstones occur in many parts of the state. Lewis enumerates:

1. Brown sandstone, or brownstone, and also gray and white sandstones abundant in Triassic belt across central part of state. The white and gray occur at many points from the Delaware to the Hudson and are much used. They consist of quartz or quartz and feldspar.

2. Conglomerates and sandstones of Kittatinny Mountain region, southwest of Greenwood Lake.

3. White to gray sandstone or quartzite in northwestern counties.

4. Reddish, purplish and bluish gray argillites around Princeton, Lawrenceville and Byram.

5. Flagstones of Hunterdon, Warren and Sussex counties. Of these the first has been most important, but the demand is less than formerly. Much of that cut below water level hardens as the stone dries out. The localities of production include Chester, Ridgefield, Watchung, Martinsville, Princeton, Wilburtha, Stockton.

Brownstone is also quarried at several points, including Little Falls, Paterson, Belleville, etc.

Examples. — Trinity Church, N. Y.; Queen's Building, Rutgers College, New Brunswick, N. J.; Old Court House, Newark, N. J.

PENNSYLVANIA.

The Triassic sandstone formation crosses Pennsylvania from New Jersey to Maryland, the chief quarries being at Hummelstown, Dauphin County.

The rock obtained there is evenly bedded, fine grained and takes a smooth finish. Two shades are quarried, the most abundant being of a dark reddish brown color, resembling the sandstone from East Longmeadow, Mass.; the other is a purplish brown. The stone is practically free from mica and has not been observed to scale off. The Hummelstown stone has been widely used.

Examples. — The Market and Fulton National Bank, New York City; Salem Lutheran Church, Lebanon, Pa.; High School, Altoona, Pa.; Presbyterian Church, Indiana, Pa.; Emory Methodist Episcopal Church, Pittsburg, Pa.; Union Station, Indianapolis, Ind.

In western Pennsylvania, there are numerous sandstones in the Coal Measures formations, but they are little used except for local purposes.

Near Pittsburg there are many quarries which produce small quantities of stone, and not a few of these are said to weather unevenly, owing to presence of calcareous matter, and are sensitive to frost.

The Wyoming County stone, known to the trade as Wyoming Valley stone, is said to resemble the New York bluestone.

MARYLAND.

There is only one sandstone within the state which has attained any reputation as a building stone and that is the so-called Triassic or "Seneca Red." There are other sandstone areas in other parts of the state, but they are quarried only for local use. The Seneca red stone is from the same formation that supplies the brownstone of Portland, Conn., and that of Hummelstown, Pa. The prominent quarries are situated near the mouth of Seneca Creek, Montgomery County. The stone occurs in workable beds varying in thickness from 18 inches to 6 or 7 feet, and these are separated from each other by bands of inferior material of different color and texture. The sandstone beds,

themselves, differ very much not only in color but also in hardness and texture.

The texture of the stone placed on the market is fine grained and uniform, not at all shaly, and shows little or no tendency to scale when exposed to the weather.

It is said to be soft enough to carve and chisel readily when quarried, but after exposure becomes hard enough to turn the edge of well-tempered tools. Its color varies from an even, light reddish brown or cinnamon to a chocolate or deep purple brown. It is brighter when first quarried.

Matthews gives several instances of the use of this stone which show its durability. The Smithsonian Institute, erected between 1848–1854, shows few defects from weathering alone.

VIRGINIA.

This state contains a number of sandstone formations, but none are worked for any except local use.

WEST VIRGINIA.

There are a number of sandstones in this state but they are mainly of local value.

ALABAMA.

In the Coal Measures area of the state, sandstones have been worked at Jasper and Cullman, and at Tuscaloosa.

The locks on the Warrior River at the last-named place are constructed of this stone.

The Hartselle (Lower Carboniferous) sandstone is quarried near Cherokee, Colbert County, and has been used for the locks at the Colbert Shoals on the Tennessee River.

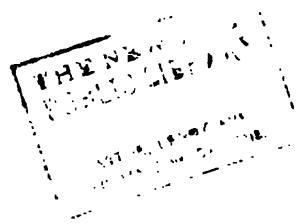
The Weisner sandstone has furnished the material for many buildings around Anniston.

CENTRAL STATES.

OHIO.

There are several sandstone-producing formations in Ohio, but by far the most important is that known as the Berea sandstone or Berea grit.

PLATE XXX. — U. S. Post Office, Toledo, Ohio, constructed of Gay "Canyon" Berea sandstone. (Photo loaned by Cleveland Stone Co.)



This stone, which is widely used for building purposes, is of fine, even-grained texture, very light buff-gray color and evenly bedded.

It is moderately porous and not extra hard, so that it can be easily carved and cut.

In the best grades the sulphide of iron (pyrite) is finely divided and evenly distributed, and on exposure to the air the stone turns yellowish. This, however, does not seem to affect the durability or appearance of the stone. If the pyrite is unevenly distributed the stone has a blotched appearance, and such pieces are undesirable.

The principal quarries are located in the town of Amherst, Berea and East Cleveland.

Examples. — Almost every large city contains structures of Berea sandstone. Among these may be mentioned: Soldiers and Sailors Memorial Hall, Pittsburg, Pa.; Goldwin Smith Hall, Cornell University, Ithaca, N. Y.; Wayne County Court House, Detroit, Mich.; City Hall, St. Louis, Mo.; U. S. Post Office and Court House, Minneapolis, Minn.

A stone known as the Euclid bluestone is obtained in Euclid and Newburgh in Cuyahoga County. It differs from the Berea in being finer grained and of a blue-gray color. Like the Berea it contains much pyrite, but does not weather uniformly, becoming blotchy. Its chief use is for bridge work, foundations and flagging.

INDIANA.

Sandstones of good quality are known in the Coal Measures formations of western Indiana, but the production is exceedingly small. Three may be mentioned.

The Mansfield sandstone lies at the base of the Coal Measures and outcrops in a band 2 to 20 miles wide and 175 miles long, extending southeast from the northern part of Warren County. It consists of quartz grains with iron oxide cement, the color sometimes being dark brown, but more often buff or gray. The former (brown) is extensively used for trimming, while the latter is quarried for local use.

The Knobstone sandstone is a fine-grained, light blue or drab-colored rock, well adapted to smooth finish or fine carving. It

is quarried somewhat extensively in Fountain County, but is not very durable unless carefully selected and set.

The Coal Measures sandstone is finer grained than the Mansfield, buff, blue or gray in color, and very durable. It is said to weather to a rusty yellow not very pleasing to the eye. This rock has been quarried in some quantity at Worthy, Vermillion County, and Cannelton, Perry County.

ILLINOIS.

Sandstones are quarried in Henry, St. Clair and Carroll counties.

MICHIGAN.

The Potsdam formation outcropping on the Upper Peninsula is the most important source of sandstone in this state. That quarried at Marquette is a moderately fine-grained sandstone, of brownish red color, often spotted with gray. The gray spots as well as the occasional presence of clay holes and flint pebbles make a careful selection of the stone necessary.

At Jacobsville, on Keweenaw Bay, the same formation supplies a stone of uniform, bright red color, even structure and texture, which has been much used for general building purposes and trimming. It is very porous, but seems to stand the weather well. The basement of the Cornell University Library is constructed of it, and after twenty years of exposure to a severe climate shows no ill effects.

Sandstones for local use are quarried in the Coal Measures formation of Southern Michigan.

WISCONSIN.

One of the most widely distributed sandstones and one which has furnished the greatest variety in color and texture is the sandstone of the Potsdam and St. Peter's formations.

The Potsdam sandstone forms a curved belt extending from the northeastern part of the state near Menominee, southwestward and then northwestward to the St. Croix River.

In this belt the stone is quarried, among other points, at Dunnville. The sandstone in general is a very light buff, although some of the beds are more of a gray or bluish white. The texture

varies from fine to coarse, and when first quarried the stone cuts easily and carves well. This stone is a good example of one, containing a very high amount of quarry water.

Examples. — Mabel Taintor Memorial Building, Menominee, Wis.; Masonic Temple, St. Paul, Minn.; Pierce County Court House, Ellsworth, Wis.

A second, but narrow, belt skirts the south shore of Lake Superior.

The latter area is known as the Lake Superior sandstone, while the large belt is known as the southern Potsdam sandstone.

The northern belt supplies a brownstone and is quarried around Bayfield and Washburn.

The stone is of a brown-red color, fine grained, not easily injured by frost, and of good fire resistance. No trouble is experienced in getting rocks of large dimensions. Some beds show clay holes, others whitish discolorations, and still others are of pebbly character, but these can be avoided in quarrying.

Several possible causes have, perhaps, reacted against the industry, viz., fashion, improper use of brownstone, and shipment of inferior stock.

The stone must not be quarried in freezing weather.

Examples of Lake Superior brownstone: Court House, Milwaukee, Wis.; Central High School, Duluth, Minn.; Court House, Washburn, Wis.; Law Building, Winnipeg, Man.; Walnut Street Opera House, Cincinnati, Ohio; Tribune Office Building, Chicago, Ill.

The St. Peter's formation forms a narrow strip, extending from the Menominee River, in a southerly and westerly direction. It is white, brown, red or yellow; medium and coarse grained, and not always hard.

MINNESOTA.

Large sandstone quarries are in operation at Sandstone on the Kettle River. The rock is a fine-grained, light pink stone, said to be hard and durable. Only about 20 feet of the 80 foot face are selected for choice building stone, and much of the upper courses is used for paving blocks and heavy masonry. Blocks 5 to 10 feet long can be easily obtained.

The approximate prices of this stone are: Rock-faced dimension stone, $1 to $1.25 per cubic foot, f.o.b.; sandstone, two sides, 50 cents per cubic foot; paving blocks, $1.50 per cubic yard.

This stone is extensively used for building purposes in the Mississippi Valley states and makes a good structural material.

Examples. — Library Building, University of Illinois; United Presbyterian Church (interior), Worcester, Mass.; Spokane Club Building, Spokane, Wash.; Des Moines, Ia., Public Library.

A good quality of quartzite is extensively quarried at New Ulm and makes a satisfactory building material.

MISSOURI.

The most important sandstone quarries in the state are located at Warrensburg and Miami. The formation supplies large blocks of sandstone of either blue or white color. Some of the stone is reedy and hence care is required in selecting it. The stone hardens on exposure to the atmosphere.

ARKANSAS.

This state is not important as a producer of sandstone but the northern part of the state, according to Branner (*Stone*, October, 1889), is said to contain a great quantity of cream-colored calciferous sandstone which, on account of its color, firmness and massiveness, makes it desirable for architectural purposes.

Gray sandstones come from coal regions of the state but are not used to any great extent.

Western States.

MONTANA.

Sandstone is quarried in between twelve and fifteen counties in the state, but the quarries near Columbus, Yellowstone County, are by far the most important. This locality supplies a sandstone of bluish color, fine grain, and unusually even texture, the latter reminding one somewhat of the Berea stone. The stone at times shows a cross-bedded structure.

Example. — Capitol at Helena, Mont.

COLORADO.

A number of good sandstones are found in this state, but owing to small demand and poor transportation facilities they are little used. The most important ones are the so-called red beds which are found at a number of points in the state. A belt

of these extends along the foothills of the mountains, passing through Manitou and Boulder. This formation supplies a variety of stone, including a bright red stone which is often used for structural purposes and white, hard sandstone and also some softer sandstone. Many of these are not very durable.

The first of these is known as the Manitou stone because it is quarried largely near that place. This stone works very easily and has been much used in public and private buildings in Denver. The harder type of sandstone, from the Red Beds, which is said by Merrill to be used for flagging and foundation, has been quarried at Bellvue, Stout and Arkins in Larimer County; at Lyons, Boulder and at other points in the foothills. This stone is a deep red color. A light-colored sandstone, somewhat resembling the Berea sandstone, has been quarried near Canyon City and was used in the construction of the Court House at Denver.

WASHINGTON.

Sandstones are found at a number of points in the state, but the chief deposits occur on the western side of the Cascade Mountains.

The Tenino stone is a fine-grained, dark-colored sandstone, with some mica, and hardens considerably after being quarried.

Examples. — High School Building, Seattle; Trinity Church, Seattle; Calvary Presbyterian Church, San Francisco, Cal.

A blue-gray Carboniferous sandstone has been quarried near Bellingham. It is fine grained and somewhat harder than the Tenino sandstone.

Examples. — U. S. Custom House, Port Townsend; U. S. Custom House, Portland, Ore.; Thurston County Court House, Olympia.

CALIFORNIA.

The most important sandstone-producing district of California is in Colusa County.

Examples. — Kohl Building, San Francisco; St. Francis Hotel, San Francisco; Jas. L. Flood Building, San Francisco.

The Leland Stanford Buildings are constructed of sandstone from south of San José, Santa Clara County. It is buff and light gray.

CHAPTER V.

LIMESTONES AND MARBLES.

Limestones and Dolomites.

Under the name of limestone there is included a group of stratified rocks which consists essentially of calcium carbonate.

They are sometimes quite impure, the common impurities, any or all of which may be present in varying amounts, being iron oxide, silica, clay and carbonaceous matter. Magnesia is likewise rarely absent, and with an increase of it the stone passes into a typical dolomite, which chemically consists of 54.35 per cent lime carbonate and 45.65 per cent magnesium carbonate.

With an increase in silica the rock passes into a calcareous sandstone; with an increase of clay, into a calcareous shale.

A limestone which has been rendered crystalline by metamorphism is termed a marble, and this type is treated under a separate heading. It may also include some limestones of crystalline texture, which have not a metamorphic origin. These may be regarded as marbles in a commercial sense, but are not strictly so geologically.

Color. Limestones show a great range of color, the most common shades being blue, gray, white and black, but other colors, due chiefly to iron compounds, may occur, although these more brilliant and beautiful colors are seen chiefly in the marbles.

Hardness. Both calcite and dolomite are soft minerals, but the rocks of which they form the main constituent are often very hard. Limestones, however, as a class, show a great variation in their hardness. Some are so soft as to be readily cut with a saw, as, for example, coral rock, the Caen stone of France, and others. The Bedford limestone of Indiana is moderately hard, while the Shenandoah limestone of the southern states is a very firm rock.

Texture. Most limestones are fine grained, indeed, so fine that the individual grains are not noticeable with the naked eye.

Plate XXXI, Fig. 1. — Limestone showing dark flint nodules.

PLATE XXXI, Fig. 2. — Tremolite in dolomitic marble.

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Some are moderately fine grained, as the oölitic limestones, while others are coarse grained, due largely to the presence of numerous fossils. The Coquina, found near St. Augustine, Fla., is to be classed with the last named.

Absorption. The majority of the harder limestones have a very low absorption, usually under two per cent. Some widely used ones may run much higher. Thus the Bedford, Ind., limestone shows 4 or 5 per cent; the French Caen stone, 10 to 12 per cent; the Roman travertine still more.

Weathering qualities. Both limestones and dolomites, if dense and massive, are moderately durable, though not to be compared with good sandstones or granites.

Limestones weather primarily by solution; that is to say, rain or surface water may slowly attack the rock, but the solution of the surface may go on very unevenly. If certain portions are silicified, such as fossils which have been replaced by silica, or if quartz veins are present in the rock, these resist the solvent action of surface waters more than the surrounding calcareous parts of the rock and are left standing out in relief, giving the stone a rough appearance.

Dolomites do not weather so readily by solution, but disintegrate, breaking off a grain at a time. This is specially noticeable in some coarse-grained ones, which have been exposed to the weather for from forty to fifty years.

Pyrite is an undesirable mineral in either limestone or dolomite.

Chert or flint should likewise be avoided. It sometimes forms lines of concretions along the bedding planes and causes the stone to split when exposed to frost action.

Crushing Strength. Most hard limestones show a good crushing strength, ranging from 9000 to 12,000 pounds per square inch.

Fire Resistance. The resistance of limestone to fire, at temperatures below that required to convert the stone into quicklime, is usually fair, although lime rock, like other kinds of stone, is apt to spall badly under the combined attack of fire and water.

Tests of Limestone. There are few complete series of published tests, but the following table, though somewhat incomplete, may serve to give some idea of their variation.

LIMESTONE.

Location of quarry.	Firm name.	Crushing Strength.				Transverse strength.		Sp. gr.	Per cent porosity.	Per cent absorption.	Weight per cu. ft.
		Position.	Max. Cr. S.	Aver. Cr. S.	Remarks.	Max. mod. rupture.	Aver. mod. rupture.				
Carthage, Mo.	Carthage Marble & White Lime Co.	B.	16,551	16,337		2,916	2,285.5	2.708	1.34	.50	167
do	do	E.	16,400	15,396							
St. Louis, Mo.	Stolle Stone Co.	B.	14,186	13,032		2,822.4	2,727.40	2.672	7.30	2.95	150.3
do	do	E.	18,182	17,349							
Bedford, Ind.	Bedford Stone Co.		5,600	5,200				2.47		4.4	154.4
Crawford, Tex.	Crawford Stone & Lime Co.		3,420	2,300				2.09			130.6
Kerrville, Tex.	B. C. Richards		2,725	2,400				1.92		12.1	118.7
Sturgeon Bay, Wis.	Washington Stone Co.	E.	35,518	30,000		3,923	3,200	2.81	0.68	0.24	175
do	do	B.	30,841								
Bridgeport, Wis.	Bridgeport Stone Co.	B.	6,675			1,164		2.74	13.02	5.46	148.7
do	do	E.	7,508								
Hannibal, Mo.	Hannibal Lime Co.	B.	10,679	9,286		1,824	1,745	2.65	5.03	2.00	157.7
do	do	E.	10,700	9,915							
Niota, Ill.			14,120		Dolomite.			2.58		0.03	161
Joliet, Ill.		B.	16,900	15,000				2.73		2.73	170
Canton, Mo.		B.	9,250	7,000				2.34		4.8	146
Marquette, Mich.		B.	7,825					2.34		4.3	146
do		E.	8,050	7,800				1.9		5.1	118.8
Caen, France		B.	3,650	3,500				1.9		5.1	118.8
Austin, Tex.	4X2.25X2.25			3,422	Court house stone			2.1616		0.068	134.76
Burnet Co., Tex.	4X2X2			14,950	Honey Creek			2.7057		0.0004	168.67
Bowling Green, Ky.	4X4X4			6,042			1,317				
Bedford, Ind.	4X4X4			9,012	Buff colored		2,058				

Chemical Composition. The following analyses are given for the benefit of those who desire to see the range in chemical composition shown by limestones which are used for structural work:

	I.	II.	III.	IV.
Calcium carbonate ($CaCO_3$)	97.26	54.53	81.43	98.91
Magnesium carbonate ($MgCO_3$)	0.37	39.41	15.04	0.58
Alumina (Al_2O_3) } Ferric oxide (Fe_2O_3) }	0.49	0.26	0.57	0.63
Silica (SiO_2)	1.69	3.96	2.89	0.10
Water (H_2O)	.....	1.50	0.08	.....

I. Bedford, Ind.; II. Newburg, N. Y.; III. Spore, Ohio; IV. Siluria, Ala.

Varieties of Limestone and Dolomites. The following variety names include those not uncommonly found in the literature. They are used for structural or ornamental work unless otherwise stated. These latter exceptions, although not properly belonging here, are mentioned because their value is sometimes misjudged.

Chalk is a fine, white, earthy limestone, composed chiefly of the shells of microscopic animals. It is of no structural value.

Coquina is a loosely cemented shell aggregate, like that found near St. Augustine, Fla. The Spaniards used blocks of this for purposes of construction.

Dolomite is a rock composed of carbonate of lime and carbonate of magnesia, in the proportions of 54.35 per cent of the former and 45.65 per cent of the latter. It may contain clayey impurities, and grades into limestone.

Fossiliferous Limestone. A general term applied to those limestones which contain fossil remains, such as shells and corals. If the stone is dense and capable of taking a polish, the lines of these fossils often add to the beauty of the stone.

Hydraulic limestone is clayey limestone containing over ten per cent of clay impurities. It is not used for building stone.

Lithographic limestone is an exceedingly fine-grained, crystalline limestone. It is used for lithographic and not for structural work. The thin, impure layers overlying the lithographic rock in the Bavarian quarries are locally used as roofing tiles.

Magnesian or Dolomitic Limestone. This is a rock intermediate in composition between a pure dolomite and a pure calcite limestone. It may show a variable composition.

Marble. This properly includes all crystalline limestones, whose grains may be either calcite or dolomite. The term marble as used commercially has a somewhat broader meaning, since it includes all limestones that will take a polish. It may, therefore, include hard, dense, non-crystalline lime rocks.

Oölitic Limestone. A limestone made up of small rounded grains of concretionary character. The Bedford limestone of Indiana and some of the soft French limestones are in part of this character.

Travertine, calcareous tufa or *calc sinter,* is a limestone deposited by streams and springs. It may be compact, but is usually quite porous, and sometimes hard enough to be used for building purposes. No deposits of commercial value are found in the United States, but an extensive deposit is worked near Tivoli in Italy, and was used, for example, in the cathedral of St. Peter in Rome. The interior of the new Pennsylvania Railroad Station in New York City is covered with it. Stalactites and stalagmites are lime carbonate deposits, formed respectively on the roof and floor of caves. They are compact and crystalline, and yield a form of marble sometimes incorrectly called onyx.

Distribution of Limestones in the United States.

Limestones are found in many states, and in all geological formations from the Cambrian up to the Tertiary. Those found in the older geologic formations are on the whole denser and harder than those found in the younger ones.

Although many large quarries have been opened to supply a local demand, the product is shipped to a distance from only a few localities. At present the Bedford, Ind., limestone is perhaps the most widely used in the United States, and is even shipped to Canada.

Only a few of the more important regions can be mentioned here. (See Plate XXXII.)

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TILDEN FOUNDATIONS

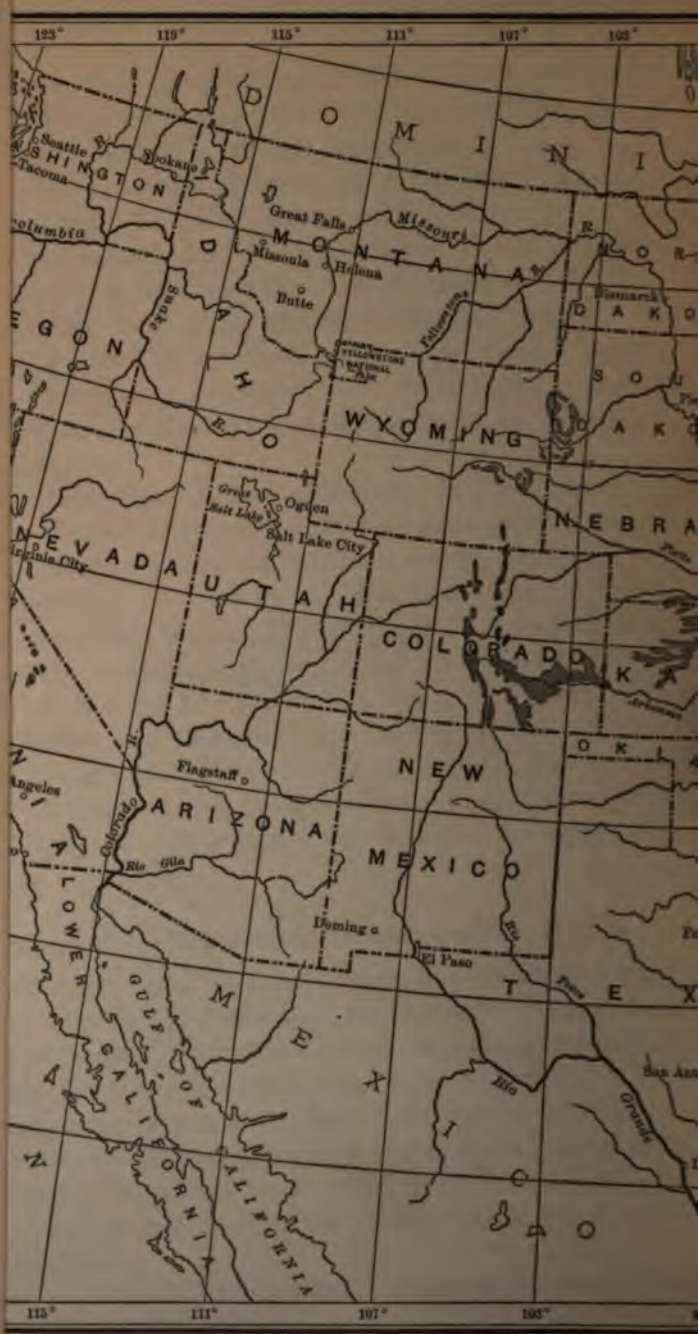

PLATE XXXII.—Map showing lim

ited States. (After U. S. Geol. Surv.)

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ASTOR, LENOX AND
TILDEN FOUNDATIONS

NEW YORK.

This state contains an abundance of hard, compact limestone, suitable for building purposes, but most of it is used only locally for foundation work, or ashlar blocks. The distribution of limestones is shown on the map (Plate XXXII). The Helderberg limestone formation extending westward through the central part of the state; the Niagara limestone between Rochester and Lockport; the Trenton limestone of the Lake Champlain belt and similar dark limestones on the northwest side of the Adirondack region are all good building stones. The crystalline limestones are referred to under marbles. The value of the stone quarried for road making and rubble far exceeds the value of that quarried for building purposes.

NEW JERSEY.

This state contains two well-known limestones, occurring chiefly in Sussex and Warren counties. Of these the most important is the *Kittatinny blue limestone*. This is massive, fine grained, usually of a quite uniform, bluish gray color, but varies in places to nearly white, or to dark grayish black. It may carry seams of chert, but has been used locally throughout the region of its occurrence and is of good durability.

Examples. — Presbyterian Chapel, Newton; Locke Hall, Blair Academy, Blairstown; Clinton Hall, same.

PENNSYLVANIA.

A vast amount of limestone is quarried in this state for flux, roads and railroad ballast. The amount extracted for building purposes is comparatively small.

A crystalline limestone, more properly described under marble, is quarried in Montgomery, Lancaster and other counties of southeastern Pennsylvania. It is of a variable color and texture and is used chiefly for ordinary construction work.

In the central and western part of the state there are a number of limestone formations, of variable character, and not usually of much thickness. They are of value only for local use.

MARYLAND.

Limestones are abundant in Maryland, but most of these have not been quarried except for local use. One of the most important is that from the Shenandoah formation of the Hagerstown and Frederick valleys.

The stone is of a deep blue color when freshly quarried, but upon exposure changes slowly to a dove gray. The stone is at many points covered by residual clay.

This same formation is important at other points in the Great Valley to the southward.

VIRGINIA.

The most important limestone formations are found west of the Blue Ridge. That known as the Shenandoah limestone is the most persistent one in the state, being the underlying rock of the Great Valley.

The rock, which often contains chert, varies from a finely granular, dark blue, nearly black rock, to a fairly coarse, light gray, crystalline one. The most important member for the production of building stone is the Natural Bridge limestone, which is a heavy bedded, dark blue to gray, magnesian limestone. Quarries have been opened up in a number of points in the Great Valley for local use.

WEST VIRGINIA.

This state contains several belts of limestone, but they have not been much used except for foundations, although it is said some of the quarries would yield a durable and beautiful rock. The oölitic limestone of Greenbrier County is thought to be of value for ornamental work.

ALABAMA.

The best limestones are found in the Lower Carboniferous and Trenton formations; and quarries have been opened in Marshall, Colbert, Franklin, Bibb, Shelby, Jefferson, St. Clair, Talladega, Calhoun, DeKalb and Etowah counties.

The best known is an oölitic limestone of Rockwood, Franklin County.

In southern Alabama, the St. Stephen's limestone, known as "chimney rock," is somewhat extensively employed. This is a soft, somewhat chalky, white limestone, which is quarried by cross-cut saw, and shaped with saw, hatchet and plane. It is used mainly for chimneys.

FLORIDA.

Little limestone is quarried in this state. On Anastasia Island, about two miles from St. Augustine, a good deal of coquina (p. 185) was formerly quarried. It was used in the construction of the old city of St. Augustine and of Fort Marion.

A somewhat soft oölitic limestone occurs in southern Florida, and has been quarried at Key West.

ILLINOIS.

Cook County is the most important producer, limestone being quarried near Chicago.

In Will County, the Niagara stone is quarried in the vicinity of Lemont and Joliet. The stone is a fine-grained, even-textured, light gray rock, in massive beds, and easily quarried. It also works readily to a smooth surface, but does not take a polish. It can be used for ornamental work. The stone is said to carry considerable quarry water, and hence cannot be quarried in freezing weather.

Other quarries are worked in Kankakee, Adams and Madison counties.

INDIANA.

The most important quarrying district of Indiana lies in Owen, Monroe and Lawrence counties, in the southwest part of the state, and supplies the well-known Bedford stone, which has acquired a wide and favorable reputation for building and ornamental purposes.

The Bedford stone is a granular stone of fine to medium grain, and either oölitic texture or made up mostly of minute fossils. In the trade the color is classed as blue, buff or mixed. The first is supposed to be the original color, and the buff to have been derived from it on weathering, but this difference in color is sometimes perceptible only in the quarry or in large blocks and

not in hand specimens. The stone hardens on exposure but should be laid on bed, as carelessness in laying is said to have caused loss. The effect of lichens, vines and plants, is also said to cause discoloration and disintegration.

Owing to its comparative softness and evenness the stone can be sawn or dressed for ornamental work.

Examples. — Library, Columbia University, New York City; City Hall, Indianapolis, Ind.; Pro-Cathedral, Minneapolis, Minn.; Capitol, Frankfort, Ky.; new wing Metropolitan Museum of Art, New York City; Eighth Church of Christ, Scientist, Chicago, Ill.

KENTUCKY.

The oölitic limestone known as the Bowling Green Oölitic from Warren County, is second in importance to the Bedford, Ind., stone. Indeed, the two are similar in appearance and general character, and occur in the same formation. It is a massive stone, the quarried blocks averaging 4 by 5 by 8 feet, and can be placed in any position in building. The fresh stone is a buff-gray, but changes on exposure to very light gray. This bleaching, which is said to be due to the evaporation of a small amount of light, volatile petroleum, may extend in twenty-five feet from the outcrop.

Examples. — Custom House and Carnegie Library, Nashville, Tenn.; Custom House, Mobile, Ala.; Residence of A. M. Lathrop, Washington, D. C.

Other limestones occur in the state and have a local value.

OHIO.

The numerous limestones and dolomites occurring in the state are used to some extent for foundation work, paving and flagging, but their main use is for lime manufacture and flux and crushed stone.

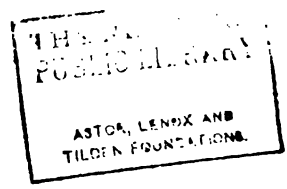
WISCONSIN.

According to Buckley a large part of Wisconsin is underlain by limestone, which extends in a broad belt through the eastern, southern and western parts of the state, and in formations known as Lower Magnesian, Trenton and Niagara.

We thus have a variety of stones, but they are mostly dolomites.

In some localities the stone is coarse grained and sugary; while in others, it is dense and finely crystalline. The limestone may

PLATE XXXIII. — Statue of Labor, cut in "Old Hoosier," Light Blue, Bedford Limestone, for City Investment Building, New York City. (Photo from Bedford Quarries Company.)


ASTOR, LENOX AND
TILDEN FOUNDATIONS.

vary even in different parts of the same formations. The colors vary from buff or straw yellow to dark bluish gray.

The largest quarries in the state are in the limestone region, but the stone is not used exclusively for building purposes.

The lower magnesian limestone quarried at Bridgeport, Trempeleau and Maiden Rock furnishes a good stone for all ordinary purposes.

The Trenton gives satisfaction where there is little or no danger from freezing, under which action it opens up along bed.

The Niagara is quarried at Wauwatosa, Lannon, Genessee, Marblehead, Sturgeon Bay and Knowles.

Examples. — Lower magnesian limestone: Wisconsin State Capitol, Madison, Wis.; Normal School Building, Madison, S. Dak.; Minneapolis stone arch bridge. Trenton limestone: Post Office, Milwaukee, Wis. Niagara limestone: Loan and Trust Building, Milwaukee, Wis.; Beloit College Chapel, Beloit, Wis.; Court House, Waukesha, Wis.

MINNESOTA.

The Minnesota limestones are all dolomitic, and the best ones for building purposes are quarried near Mankato and Kasota in the south-central portion of the state near the Minnesota River. These stones, which are very fine grained and crystalline, resemble sandstone in appearance and have an excellent reputation. They are usually some shade of yellow or yellowish brown, and take a fair polish.

Examples. — This dolomite was extensively used for interior work in the Minnesota State Capitol, and much of it has been shipped to other states. It was also employed for much of the interior work of St. John the Divine Cathedral, in New York City. The U. S. Post Office Building at Aberdeen, S. Dak., is faced with Kasota cut stone, and much of the marble wainscoting in the Minnesota State Capitol at St. Paul is polished Kasota stone.

Much dolomitic limestone has been quarried for local use around the "Twin Cities." It is used chiefly for foundations, but splits rapidly, is full of concretions and not of a pleasing color.

The Mankato stone, which is used largely for massive masonry, is a buff color, while the Kasota rock is used for finer building purposes and is a light pink shade.

Kasota cut stone, tool faced, is approximately $1.25 per cubic foot; polished work, 50 to 75 cents per square foot, depending on color.

MISSOURI.

Limestone formations are known to underlie an extensive area in Missouri, probably two-thirds of them belonging to the Lower Carboniferous formation.

Of these the Burlington formation is the most important, since it supplies the greatest amount of cut and sawed stone of any of the formations in the state.

This stone, which is extensively quarried around Carthage as well as Phenix and Hannibal, is of a uniform light, almost white color, and is strong and durable. It can, moreover, be quarried in blocks of large dimensions.

The stone is more difficult to cut and dress than Bedford stone, but is lighter and more uniformly colored, also stronger and denser.

It takes a good polish and has been much used in monumental work, but one difficulty has been the obtaining of large pieces free from suture joints. Flint nodules are found at definite horizons in the formation, and have to be avoided.

Examples. — Carnegie Library, Joplin, Mo.; Stillwell Hotel, Pittsburgh, Kans.; Public Library, Kansas City, Mo.; Ex-Confederate Monument, Ft. Smith, Ark.

While this is the most important limestone quarried in the state, there are others which are worked to a minor extent.

In southern Missouri the dolomites of the Cambro-Ordovician formation are extensively used for building. This includes the so-called cotton rock quarried around Jefferson City.

In southern Missouri there are also finer-grained limestones, somewhat resembling marble.

Around Stee Genevieve the Trenton limestone supplies a good building material, but the same formation around St. Louis is soft and undesirable.

Near St. Louis, the St. Louis limestone is extensively quarried for rough masonry.

IOWA.

Limestones form the most important building stones of the state, and some of them are dolomitic in their character, but all are worked chiefly for local use.

KANSAS.

This state contains some limestones, but few are of importance.

TEXAS.

Limestones suitable for building purposes occur abundantly in the vicinity of Austin, Texas. They are known as the Glen Rose limestone, northwest of Austin; the Edwards limestone, outcropping along the Colorado River, and the Austin chalk, within the city limits.

CORDILLERAN REGION.

In the territory extending from the eastern edge of the Rocky Mountains to the Pacific Coast, there are scattered limestone formations, but few are quarried, except for local purposes, the more abundant igneous rocks being often preferred. Many of those occurring in this region lack development partly because there is no demand for them.

Limestones are known in Colorado but they are usually too impure and not massive enough for building purposes.

MARBLES.

Under this term there are properly included those limestones or dolomites which have a crystalline texture and are susceptible of taking a good polish. The term marble has, however, come to be somewhat loosely used in the trade, and is often applied to any limestone which will take a polish, whether it is crystalline or not. Marbles are used chiefly for ornamental work and the better grades of construction.

Mineral Composition. Marbles, when pure, are composed of calcite, dolomite or a mixture of the two. Other minerals are not infrequently present and are often to be regarded as injurious impurities. The following are not uncommon.

Mica. This occurs usually in fine scales, not always of the same species, and these small scales are present often in bands, usually of a wavy nature, or in blotches. Mica in small amounts is not very harmful, but if abundant it interferes with the continuity of the polish and lowers the weather-resisting qualities of the stone, the mica decaying and leaving a pitted surface. Marbles containing an abundance of mica are, therefore, not adapted to exterior work in a severe climate. It is no doubt true

that the bands and cloudings of mica often add to the beauty of the stone, but it is better to sacrifice a little ornamental value rather than to select a stone which is sure to disintegrate in the course of a few years. Architects would do well to give more heed to this matter than many of them do. The author has observed columns of cipolino marble, in New York City, which were seriously affected after three years' exposure to the weather.

Pyrite is present in small scattered grains in some marbles. Such stones should be avoided as much as possible, as pyrite rusts easily and, in so doing, yields sulphuric acid which still further attacks the stone.

Tremolite (Plate XXXI, Fig. 2) is a mineral impurity of some dolomitic marbles and its light colored, silky lustred grains, when fresh, are easily recognizable. It weathers somewhat easily to a clayey material, so that, if abundant, the surface of the stone may become pitted as the tremolite weathers out. In some quarries the tremolite has been found to occur abundantly in certain parts of the quarry.

Quartz, may occur in some marbles as veins, concretions or thin layers. Such stone should be rejected.

Carbon is the cause of the gray, blue-gray and black color seen in many marbles (Plate XXXVI, Fig. 2). It may color them uniformly or form cloudy patches and bands, thus adding greatly to the beauty of the stone.

Iron oxide is found in many marbles, and is responsible for the beautiful red, yellow, brown and pink colorings shown by many of them.

Color. Marbles show a great range of colors; some are snow white, others gray to black; still others may show varying and often beautiful shades of red, pink, yellow, green, brown, etc.

Texture. The texture of marbles may range from those of exceedingly fine grain to those which are very coarse, having grains a quarter of an inch in diameter. The medium to fine-grained ones are to be preferred.

Some ornamental marbles show a *brecciated structure.* That is, they are made up of angular particles of crushed rock, the interstices between them being filled, in part, by secondarily

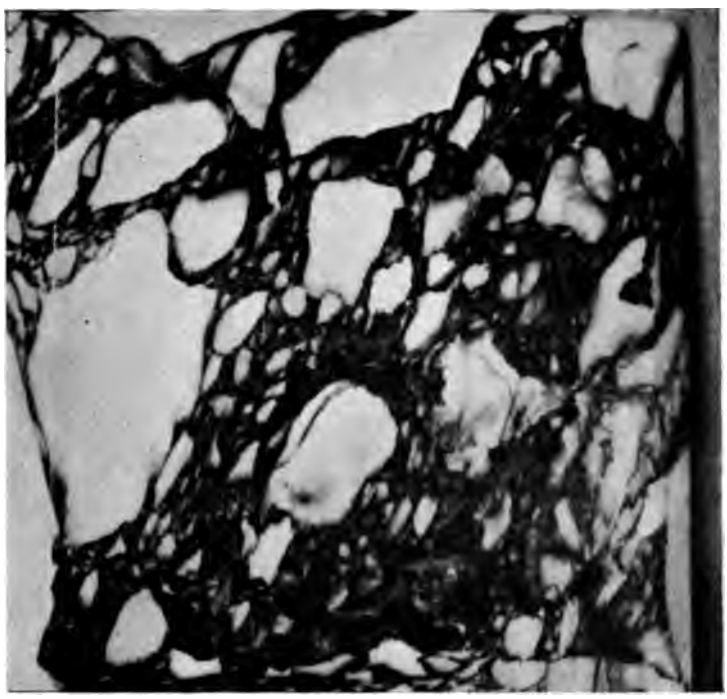


PLATE XXXIV. — A decorative marble, showing a brecciated structure.

deposited mineral matter. Such stones are often of great ornamental value, but they lack in durability and should not be used for exterior work in a severe climate, a fact too often overlooked by many architects.

Weathering Qualities. What has been said regarding the weathering qualities of limestone is equally true of the marbles. It may be added that those with a brecciated structure and of micaceous character are much less durable than the average limestone.

Absorption. The absorption of marbles is always low, usually under one per cent.

Crushing and Transverse Strength. A few tests taken from different sources are given in the table printed below.

Uses of Marbles. Marbles are being used in increasing quantities for ordinary structural work, although many of the lighter colored ones soon become soiled by dust and smoke. The product of many quarries, especially the Vermont ones, is well adapted to monumental purposes, as are also those from Georgia.

TESTS OF MARBLE.

Location of quarry.	Firm name.	Crushing strength.				Transverse strength.	Sp. gr.	Per cent absorption.	Weight per cu. ft.
		Position.	Max. Cr. S.	Aver. Cr. S.	Remarks.	Aver. mod. rup.			
Colville, Wash.	Crystal Marble Co.		24,000	19,000			2.87	0.16	178
South Dover, N. Y.	South Dover Marble Co.		20,882	19,000			2.86	0.267	
Tate, Ga.	Georgia Marble Co.	B.	13,680	12,800	"Kennesaw Marble"		2.71	0.008	169
Marble Hill, Ga.	Southern Marble Co.	B.	13,696	13,300			2.73	0.006	171.8
Tennessee			18,100	16,500				0.008	
Cockeysville, Md.			20,400	16,000					175
Dorset, Vt.		B.	7,612				2.63	0.58	164.7
Tuckahoe, N. Y.		B.	13,700				2.80		175
Rutland, Vt.			13,600		White	1,202			
Rutland, Vt.			11,892		Blue	2,057			
De Kalb, N. Y.	T. S. Clarkson		13,864		Richville white marble	838			
			13,733						

Among the other uses of marble are its application for wainscoting and paneling, floor tiles, electrical switchboards and sanitary ware. If used for tiling floors it is often preferable to use but one kind, as marbles of different colors may be of unequal hardness, and hence a floor, over which there is much passing, may wear uneven in a comparatively short time. Many of the black and white tiled marble floors show this. The demand for marble tops for tables and washbasins is probably decreasing.

Many beautiful decorative effects are produced by sawing a slab of colored or patterned marble in two or more slices and matching these together (Plate XXXV).

Distribution of Marbles in the United States. Marbles are less widely distributed than limestones, since they occur almost exclusively in areas of metamorphic rock. Most of those quarried are white, few being of variegated color. Indeed, the larger part of the beautiful decorative ones with which most of us are familiar are imported from foreign countries.

Vermont leads all other states in the quarrying of marble, but Georgia and Tennessee are also important producers.

The more important occurrences are referred to below.

VERMONT.

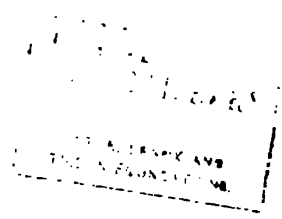
The Vermont marble deposits begin on the south at Dorset Mountain and extend northward in a narrow belt through Wallingford, West Rutland, Pittsford and Brandon to Middlebury. These are all true marbles or metamorphosed limestones. Another important locality has been opened up farther north at Swanton, but this is not a true marble.

The marble used for building purposes varies from 75 cents to $2.00 per cubic foot, while that for monumental work may bring from $5 to $7, and statuary marble as much as $12.

Those marbles quarried at Dorset are more coarsely crystalline than those quarried in the West Rutland area.

It can be said that in general the Vermont marbles usually show a bluish gray or whitish ground, the latter often showing a pinkish or creamy shade, and traversed by veins or markings, more or less distinct, of a green or brown color.

PLATE XXXV. — Interior of Harris County Court House, Houston, Tex., showing creole matched marble.
(Photo from Georgia Marble Company.)



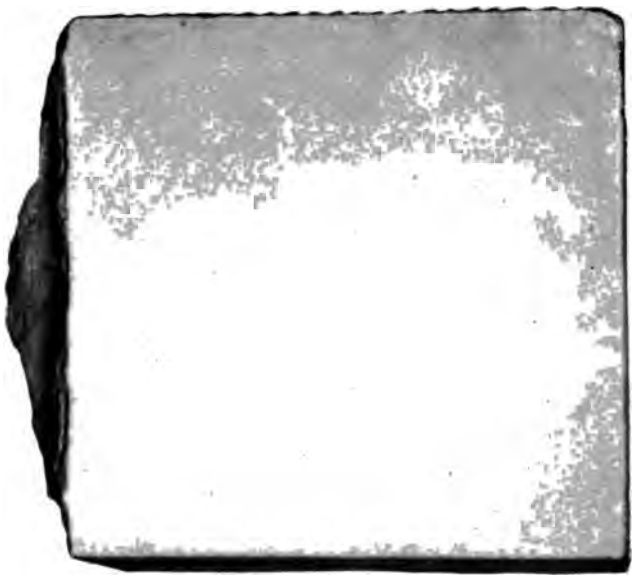
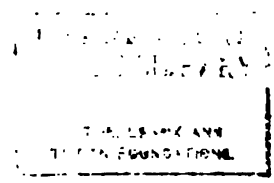


PLATE XXXVI, Fig. 1. — White marble, Vermont.

PLATE XXXVI, Fig. 2. — Gray marble, Vermont. (The color is due to carbonaceous matter.)



Not infrequently several different varieties or shades are found in the same quarry. The following section brings this point out well, and shows the section found in the West Rutland quarries of the Vermont Marble Company.

Blue marble, top } White marble }	20 feet.
Green striped	2 feet.
White statuary	5–6 feet.
Striped monumental	2–6 feet.
White statuary	3–6 feet.
Layer partly green, partly white	4 feet.
Green and white, " Brocadillo "	2½–3 feet.
Crinkly, siliceous layer, half light, half dark	2–3 feet.
Light and mottled	4–6 feet.
Green striped	6 inches.
White	2½ inches.
Half dark green, half white	3–6 inches.
Italian blue	15–20 inches.
Mottled limestone	

The following are varieties quarried in Vermont:

LIGHT MARBLES.

Best Light Cloud Rutland. Very light, mostly white, with very indistinct veinings, which show little, except on a polished surface. Quarried at West Rutland by Vermont Marble Company.

Blue Building. A bluish gray stone, with whitish spots, and occasional white veins. Mainly for building, but also polishes. Quarried at Fowler by Rutland-Florence Marble Company.

Brandon-Italian. Resembles ordinary veined imported Italian. General ground white, with indistinct dark bluish veins or lines or sometimes spots or blotches. Quarried by Brandon-Italian Marble Company.

Brandon-Italian, High Street Variety. Similar to preceding, but usually darker. Quarried by same company.

Brocadillo. Might be classed with fancy varieties. Resembles Listavena, but is darker and has greater abundance of green veins, which are sometimes very abundant and pronounced. Quarried at West Rutland by Vermont Marble Company.

Dorset Dark Green Vein. Nearly white marble in some examples and greenish in others. White ground, cut by numerous green lines, veins, bands or blotches, so arranged that slabs

can be matched to form figures in a panel. There are also blotches.

Examples. — Interior paneling of Albany Commercial Bank; Four-piece panels, some of the latter being 18 feet high and 13 feet wide; Twenty-five columns in exhibition room of New York City Library; Interior of American Trust and Securities Building, Chicago.

Dorset White. Appears pure white from distance, but upon close examination shows delicate light brown or smoky bands or veins. The Dorset marbles are harder and more coarsely crystalline than those of the Rutland district.

Example. — The New York Public Library Building on Fifth Avenue is built of this marble.

Florence. For monuments and building. Bluish white ground clouded and veined with dark shades, varying from smoky to black. Quarried at Fowler by Rutland-Florence Marble Company.

Gray Building. General tone bluish gray, slightly mottled with white and veined with dark shades. Veins usually quite fine. Quarried at West Rutland by Vermont Marble Company.

Italio. A moderately light marble, with bluish white ground, and darker bluish cloudings. Quarried at Columbian quarry, Proctor, by Vermont Marble Company.

Light Florence. Resembles some of the light Italian marbles. Ground white with bluish cast, thickly clouded and streaked by dark spots and lines. Markings more regular than those of many Vermont marbles. Quarried at Fowler by the Rutland-Florence Marble Company.

Light Green Cloud. A Dorset marble of clear white ground, with scattered greenish clouds and patches. Some of these are dark. A good building marble, but used especially in interiors. Quarried at Dorset by the Norcross-West Marble Company.

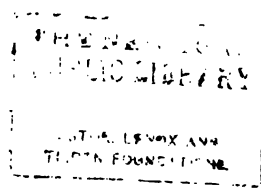
Light Sutherland Falls. Nearly pure white ground, with veins, usually of a bluish white color. Quarried at Proctor.

Listavena. Green and white bands. West Rutland.

Mountain White. Very light, with occasional brownish veins. Quarried at Danby by Vermont Marble Company. Much has been used in New Senate Building in Washington, including sixty large columns.

PLATE XXXVII, Fig. 1. — Quarries in Travertine near Tivoli, Italy.
(Photo by J. C. Branner.)

PLATE XXXVII, Fig. 2. — Quarry of Vermont Marble Company, Proctor, Vt.
(Photo loaned by Vermont Marble Company.)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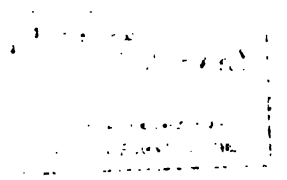
ASTOR, LENOX AND TILDEN FOUNDATIONS

PLATE XXXVIII. — Kimball Monument, Chicago, Ill. Done in Vermont white marble. (Photo loaned by Vermont Marble Company.)



Pittsford-Italian. Light with yellowish brown lines. Quarried at Pittsford, by Rutland-Florence Marble Company.

Pittsford Valley. First quality. Resembles Sutherland Falls.

Plateau White. Very light with irregular creamy and greenish bands. A hard, durable marble.

Example. — New Harvard Medical Buildings. Quarried at Dorset by Norcross-West Marble Company.

Statuary. A very white layer, quarried at West Rutland.

DARK MARBLES.

These include those in which black, dark green or blue predominate over lighter shades or white. They are not so commonly used for building stones as the lighter varieties, but are very effective when rock faced. Their main use would seem to be for interior finish. They are occasionally used for monuments. Some of the black ones are not true metamorphic limestones.

Black or Fisk Black. This, properly, is a limestone. It is a dark gray or gray-black limestone. Not extensively used.

Dark Florence. Bluish ground, with lighter veins. Quarried at Fowler, by Rutland-Florence Marble Company.

Dark Vein Esperanza. One of the darker Vermont ones. West Rutland.

Dark Vein or True Blue. West Rutland.

Extra Dark, Mottled True Blue.

Extra Dark, Royal Blue. Darkest marble found in Rutland area.

Other varieties are: *Extra Dark Vein True Blue; Florentine Blue; Highland Blue; Livido.*

ORNAMENTAL OR FANCY MARBLES.

Many of these are not as brightly colored as some of the imported ones, but they often show very decorative effects. Among them may be mentioned:

Æolian.

American Pavonazzo. Dark green veins on a beautifully tinted creamy ground. Quarried at West Rutland by Vermont Marble Company.

American Yellow Pavonazzo. Color mainly light salmon, with yellow or creamy tints. Quarried at West Rutland by Vermont Marble Company.

Columbia Listavena. Light yellow ground, with veining of gray, light brown or olive. Quarried at West Rutland by Vermont Marble Company.

Olivo. A Rutland marble similar to Brocadillo.

Pink Listavena. Salmon ground, greenish veins.

Rosaro. Light yellow with delicate light olive veins.

Rubio. Delicate pink ground inclining to salmon, and indefinite veinings of light green. Quarried at West Rutland.

Verdoso. A green-shaded West Rutland marble.

Verdura. A greenish marble from West Rutland.

Champlain Marbles. These are Lower Cambrian Red Sandrock, being an unusually calcareous portion of the same, and grade into each other. With one exception they are all quarried at Swanton and by the Barney Marble Company. They all contain much silica and iron and are predominantly shades of red and white. Being harder than marble, they take a more brilliant and durable polish. For the same reason they are more costly to saw and finish, but are used for flooring and wainscoting all over the United States. The varieties are Jasper, Lyonnaise, Olive, Royal Red and Oriental Verde.

Examples of Vermont Marbles. — The following list of buildings constructed wholly or in part of Vermont marble, have been supplied by several companies:

Vermont Marble Co.: U. S. Post Office and Court House, Worcester, Mass.; Sutherland Falls marble; U. S. Post Office and Court House, Montpelier, Vt., the same; Hart Memorial Library, Troy, N. Y., Rutland white marble; Clio Hall, Princeton College, Princeton, N. J., Sutherland Falls marble; Second National Bank Building, Paterson, N. J., the same; Altar, Church of the Sacred Heart, Shelby, Ohio, Rutland white marble; Stock Exchange, Chicago, Ill., restaurant and ceiling, Listavena and White; Columbia Bank, Pittsburg, Pa., all interior finish Brocadillo; Hibbs Building, Washington, D. C.; Planters Loan and Savings Bank, Augusta, Ga.; Interior marble, Office Building, House of Representatives, Washington, D. C.; Marble for Gardens, J. D. Rockefeller, Pocantico Hills, N. Y., Rutland-Florence Marble, Fowler, Vt.

Brandon-Italian, Middlebury, Vt.: Exterior Memorial Church, Middlebury; Public School Building, Hudson, N. Y.; Annex to Fanny Allen Hospital, Burlington, Vt. This marble is used mainly for interior and vaults.

Examples of Champlain Marbles. The following list is supplied by the company:

Red marble: Government Building, Troy, N. Y.; Metropolitan Museum of Art, New York City; Government Building, Denver, Colo.; Congressional Library, Washington, D. C.; Planters Hotel, St. Louis, Mo.; Auditorium Hotel, Chicago, Ill.; Union Station, Toronto, Canada.

Red and green marble: Erie Savings Bank, Buffalo, N. Y.; Albany Savings Bank, Albany, N. Y.; Government Building, Omaha, Neb.; Philadelphia Mint, Philadelphia, Pa.; New St. Charles Hotel, New Orleans, La.

Green marble: New Southern Terminal Station, Boston, Mass.; Hotel Raleigh, Washington, D. C.; Pittsburg and Lake Erie Depot, Pittsburg, Pa.

MASSACHUSETTS.

A rather fine-grained, snow-white marble has been quarried for a number of years at Lee in western Massachusetts. Its chief use is for structural work.

Examples. — Wings of Capitol, Washington, D. C.; Public Buildings, Philadelphia, Pa.; Court House, Baltimore, Md.; Metropolitan Insurance Building and Clearing House, New York City; State House Annex and new Commonwealth Trust Co., Building, Boston, Mass.; Interior work, Gen. Grant's Tomb, and Plaza Hotel, New York City.

CONNECTICUT.

In northern Litchfield County, near East Canaan, a white, moderately coarse dolomite occurs, but it has been little worked in recent years. The stone weathers well, but, like the Lee (Mass.) dolomite, often contains crystals of tremolite.

Example. — The State House at Hartford, Conn.

NEW YORK.

Southeastern New York contains a number of beds of dolomite marble. This has been quarried at Tuckahoe, Pleasantville and South Dover.

The Tuckahoe stone is moderately coarse grained and pure white, but turns grayish on exposure to the air, as the coarse-grained surface catches the dust.

Examples. — St. Patrick's Cathedral, New York City; Metropolitan Life Insurance Building, New York City.

The South Dover marble is finer grained than the Tuckahoe, but also of white color. It has been used mainly for ordinary structural work.

Examples. — Tiffany Building, New York City; Essex County Court House, Newark, N. J.

A moderately coarse-grained, light gray, or grayish white dolomite marble is quarried near Gouverneur, St. Lawrence County. It is well adapted for ordinary structural work, and for inscriptional purposes shows a good contrast between the polished and hammered surface.

Some dense limestones, susceptible of taking a good polish, have been quarried to a small extent in Clinton County, near Plattsburg and Chazy.[1]

The one known as Lepanto marble is a fine-grained gray stone, with pink and white fossil remains. The other, known as French gray, is more uniformly gray and bears larger fossils. Both are quite ornamental, but their use has declined.

A black limestone known as black marble has been quarried at Glens Falls.

PENNSYLVANIA.

A white dolomite marble of sugary texture is quarried at Avondale, Chester County. It is used for structural work.

There are a number of occurrences of crystalline limestone in southeastern Pennsylvania, but few of them are worked for marble.

MARYLAND.

The two marble-producing localities are Cockeysville and Texas, and although they are quite close together the marbles differ from each other in purity and texture.

The Texas stone is a coarse-grained, calcite marble and is not used now for building purposes, although some of it was quarried and placed in the lower 150 feet of the Washington monument.[2]

The Cockeysville marble is a fine-grained dolomite, well adapted for building and decorative use. It is clear white in color with occasional streaks of pale gray, but care has to be used to avoid streaks of silicate minerals which occur here and there in the quarry.

Examples. — Washington Monument, Mt. Vernon Place, Baltimore, Md., erected in 1829; 108 monoliths, 26 feet long, for National Capitol; U. S. Post Office Building, Washington; Drexel and Penn Mutual Insurance Building, Philadelphia, Pa.; Spires of St. Patrick's Cathedral, New York City; Art Museum, Pan-American Exposition, Buffalo, N. Y.

[1] Merrill, "Stones for Building and Decoration." [2] Ibid.

A curious stone is that known as the Calico marble, quarried at the Point of Rocks, Frederick County. It is a conglomerate, made up of limestone pebbles which average two to three inches in diameter. The rounded and angular fragments are gray to dark blue in color. The pebbly character of the stone and irregularity in hardness make it difficult to polish and work.

Example. — Columns of this marble are in the old House of Representatives now used by the Supreme Court.

VIRGINIA.

While crystalline limestones occur in Virginia, still the state is of little importance as a marble producer. The principal localities found west of the Blue Ridge may be described as follows:

New Market and Woodstock, A coarse-textured, dun-colored marble, capable of taking a good polish; *New Market*, A mottled bluish marble, somewhat coarser grained than preceding; *Buchanan*, Gray marble of fine gray character; *Lexington*, White, fine-grained marble, capable of taking a good polish; *Giles County*, Red marble; *Blacksburg*, Black, fine-grained marble, taking high polish; *Rockingham County*, shaded yellowish gray and slate-colored marble taking high polish. Only the last has been worked for commercial purposes.

NORTH CAROLINA.

A narrow strip of marble is found in Cherokee County, N. C., which is a continuation of the beds in Fannin County, Ga.

The stone is medium to fine grained in texture, and of two distinct colors, viz., a blue gray more or less mottled and streaked with white, and almost pure white.

The marble belt lies between schists and quartzites, and near its contact with these the marble is apt to contain tremolite, talc and quartz.

The stone takes a good polish and shows good contrast between polished and hammered surface.

In Swain County there are beds of marble of varying colors, from gray to black, cream white and pink, various mixtures, and sometimes greenish.

TENNESSEE.

The marbles of the valley region of east Tennessee are well known. They are moderately coarse grained, of variable color and often highly fossiliferous. The best-known variety is a fossiliferous dark chocolate rock, variegated with white. Much of the ornamental beauty of this stone is due to the patterning produced by the white fossils in the rock. In addition to the dark chocolate colored stone, there is a lighter colored gray and pink, variety which is extensively used for wainscoting.

All the Tennessee marbles take a good, durable polish and cut to a sharp edge. They are used for paneling, wainscoting, furniture tops, switchboards, and, less often, monumental purposes.

GEORGIA.

The calcitic marbles thus far worked on a commercial scale occur along the Louisville and Nashville Railroad in the northern part of the state. The most important deposits being found in Pickens County.

The stone is coarsely crystalline and often micaceous. The color is white, white with streaks or blotches of black, gray and pink colors. In some the banding is very pronounced, and highly ornamental matched slabs are produced.

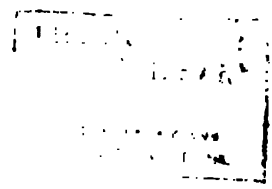
Among the varieties produced, the following may be mentioned:

Cherokee, white calcite; *Creole*, black and white mottled, coarse grained, calcitic; *Etowah*, flesh colored, coarse grained, calcitic; *Southern*, white with bluish gray markings; *Silver Gray Cherokee*, bluish gray.

The Georgia marbles have, in recent years, been extensively used for constructional and monumental work, some splendid pieces of work being seen at a number of points. The following may be mentioned among others.

Examples. — Minnesota State Capitol, St. Paul, Minn.; Rhode Island State Capitol, Providence, R. I.; Carnegie Public Library, Atlanta, Ga.; Façade of New York Stock Exchange, New York, N. Y.; The State Savings Bank, Detroit, Mich.; Corcoran Art Gallery, Washington, D. C.; Girard Trust and Banking Company, Philadelphia, Pa.; New Orleans Court House, New Orleans, La.; Royal Bank of Canada, Montreal, Can.; LaSalle Street Station, Chicago, Ill.; Royal Insurance Building, San Francisco, Cal.

PLATE XXXIX. — Monolith of marble, 27 feet 2 inches by 4 feet 4 inches, by 4 feet 3 inches; weight 50 tons. (Southern Marble Company, Marble Hill, Ga.)



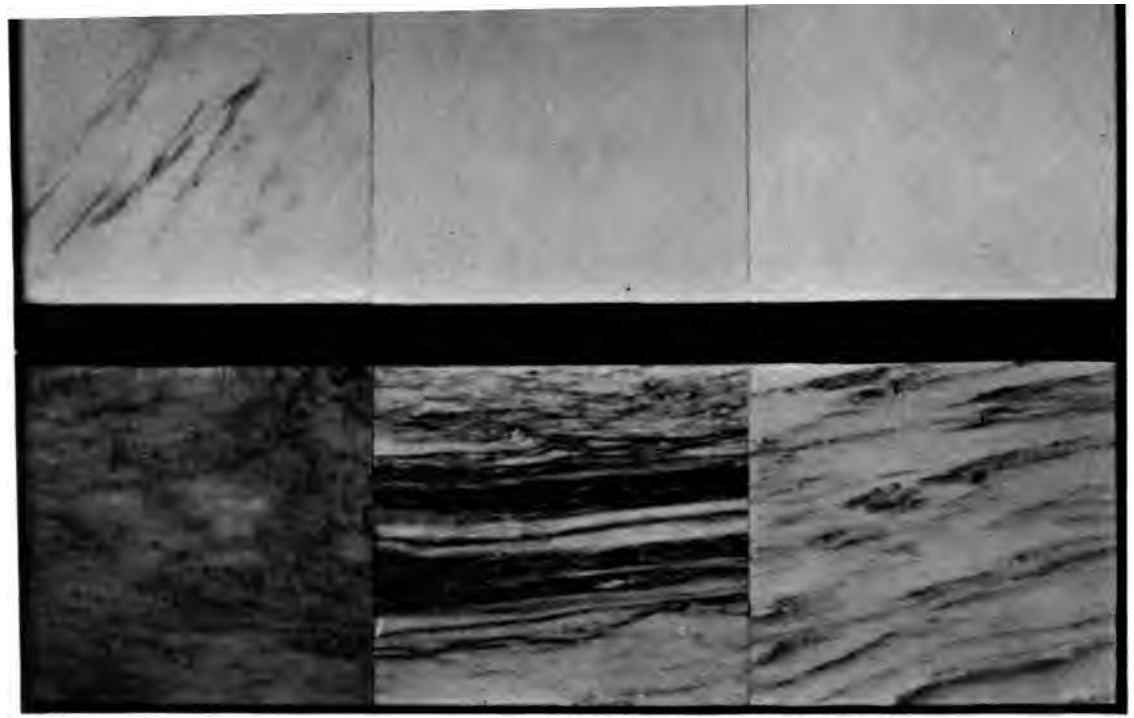


PLATE XL. — Slabs of Alabama marble, showing variation from pure white to those which are clouded and streaked with mica.

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ALABAMA.

According to Smith, true marbles occur mainly in a narrow valley along the western border of metamorphic rocks, extending from the northwestern part of Coosa County through Talladega into Calhoun. The best known are in Talladega County, and the principal quarries from which stone has been obtained are near Sylacauga and Taylor's mill.

Some of the marble is fine grained and very white, closely resembling Carrara marble; other types are cream colored, clouded, or streaked with micaceous and talcose streaks. The last two are undesirable for exterior work.

Some of the varieties are *Pocahontas*, *Alabama sunset*, *Alabama iris*, etc.

Examples. — In rotunda and other parts of main story of new Custom House, also in Night and Day Bank, New York City; National Metropolitan Bank, Washington, D. C.; exterior Maryland Institute, Baltimore, Md.

MISSOURI.

This state does not produce any true marble, but the dense, light cream white limestone quarried near Carthage is often classed as such in the trade. This stone takes a polish and might be classed as a monotone marble.

Examples. — Denkman Memorial Library at Rock Island, Ill.; Court House, Butler, Mo.; for interior work of Masonic Temple, Wichita, Kan.

COLORADO.

Marble deposits have been opened up in recent years at the head of Yule Creek, Gunnison County. The stone is fine grained, and the following types are said to occur: (1) White statuary marble, pure white, very fine grained, and takes good polish; (2) Streaked black and white with serpentine veins; (3) Blue-black, shading into blue-gray with blotches and veins of green serpentine; (4) Streaked, dark mottled, soft blue-gray to black with a few lines of jet black cut by green veinlets of serpentine; (5) Pale flesh, or pinkish chocolate, mottled and generally light.

ARIZONA.

Some decorative marble has recently been quarried in Arizona. The varieties advertised are: *Arizona Opal*, white with creamy

yellow and pink, with light pink veins; *Arizona Pavonazzo*, strong creamy white and light pinkish tone with a few strong black veins ; *Arizona Pavonazzo*, heavy veins.

CALIFORNIA.

A dolomitic marble is quarried north of Keeler, Inyo County. The stone is generally fine grained and takes a good polish. Among the varieties are a white, mottled white, gray, yellow and black. The streaked grayish black and white has been much used for wainscoting. The black is used for flooring.

CHAPTER VI.

SLATE.

On an earlier page it was explained that slate is a metamorphic rock, having a more or less perfect cleavage, because of which it has a number of commercial uses.

Slate is fine grained and varies in color from black or gray to red, green and purple. The lustre is usually dull, but some slate is quite lustrous.

Slates are derived by metamorphism, chiefly from sedimentary rock (shales), and the classification of these is given by Dale as follows:

(*A*) *Clay Slates.* Purple red of Penrhyn, Wales; black of Martinsburg, W. Va.

(*B*) *Mica Slates.*

(1) Fading:

(*a*) Carbonaceous or graphitic (blackish).
Lehigh and Northampton counties, Pa.; Benson, Vt.

(*b*) Chloritic (greenish).
"Sea green," Vermont.

(*c*) Hematitic and chloritic (purplish).
Purplish of Pawlet and Poultney, Vt.

(2) Unfading:

(*a*) Graphitic.
Peachbottom of Pa. and Md.; Arvonia, Va.; Northfield, Vt.; Brownville, Monson, Me.; North Blanchard, Me.; West Monson, Me.

(*b*) Hematitic (reddish).
Granville, Hampton, N. Y.; Polk County, Ark.

(*c*) Chloritic (greenish).
"Unfading green," Vermont.

(*d*) Hematitic and chloritic (purplish).
Purplish of Fairhaven, Vt.; Thurston, Md.

In the clay slates the particles are merely compressed by weight or pressure and cemented by carbonates of lime and magnesia, by clay and iron oxide. Their cleavability, strength and elasticity are low.

The mica slates have an abundance of mica scales developed by metamorphism and possess a high grade of fissility, strength and elasticity.

There is, however, much variation in composition and structure even within this second group — the mica slates. Thus the amount of ferrous carbonate determines the liability to discolor on exposure to the atmosphere, those containing much being of a fading character. This gives us the division of fading and unfading slates.

The slaty cleavage is an important property which has been already referred to. As a rule, it is not coincident with the bedding, but may form almost any angle with it.

Repeated freezing and thawing has a disastrous effect on the cleavability of slates, and the material must be split when fresh from the quarry.

Many slates show extremely fine plications on their cleavage surfaces, and to this the name of *bate* or *false* cleavage is given by the quarrymen.

The *slip cleavage* consists of minute plications, which result in microscopic slips or faults along which the slate breaks easily.

Grain is a direction along which the slate can be split, but not as smoothly as along the true cleavage. The grain is indicated by a somewhat obscure striation on the cleavage surface in a direction nearly parallel to the cleavage dip.

Joints are found in all slate quarries and may traverse the slate in various directions. The term *Post* is applied to a mass of slate traversed by so many joints as to be useless. ***Ribbons*** are lines of bedding, or thin beds, which show on the cleavage surface and are often of a different color. If irregular and numerous, they may make the slate worthless, but in many cases do no harm.

Veins of quartz or calcite occur in some quarries and render those portions of the slate in which they are found worthless. Pyrite in lumps or grains is equally injurious.

PLATE XLI, Fig. 1. Slate quarry, Penrhyn, Pa. (Photo by H. Ries.)

PLATE XLI, Fig. 2. — Splitting slate. (Photo by H. Ries.)

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The chemical analysis of slate is of little value in most cases, except for purposes of scientific study, although those slates which are most likely to discolor seem to contain greater amounts of ferrous carbonate.

PROPERTIES OF SLATE.

The physical characters of slate are mostly so different from those of other building stones that a special series of tests is usually necessary. These properties and tests may be referred to separately.

Sonorousness. If a good-sized piece of roofing slate of the usual thinness is suspended and struck with some hard object it will emit a ring like semi-vitreous china. Mica slates are more sonorous than clay slates, but those with considerable chlorite may be deficient in this respect.

Cleavability. The slate is split with a thin chisel about two inches wide, in order to determine the smoothness, thinness and regularity with which it cleaves.

Cross Fracture (Sculping). This property, which should be tested by an experienced person, is to determine the character of the grain.

Character of Cleavage Surface. It should be noted whether or not the slate cleaves smoothly.

Lime. A drop of cold, dilute muriatic acid applied to the edges of a freshly quarried slate will, by the effervescence, indicate the presence of lime. Slates containing a large amount of lime carbonate are more likely to be acted upon by acids in the atmosphere.

Color and Discoloration. The value of a roofing slate depends somewhat upon its permanence of color. To obtain information on this point the fresh slate should be compared with pieces which have lain on the dump for several years, or pieces on the roof.

Presence of Clay. If much is present, the slate will emit an argillaceous odor when breathed upon, but the very best slates do not.

Presence of Marcasite. Good slates should be free from this form of iron sulphide, which is recognized by its yellowish color and metallic lustre. The objection to it is that it decomposes to limonite.

Strength. The transverse strength of slate is of importance and should be determined. In the best slates the modulus of rupture should range from 7000 to 10,000 pounds. An impact test devised by Merriman is as follows: A wooden ball weighing 15.7 ounces is allowed to fall 9 inches upon a piece of slate 6 by $7\frac{3}{4}$ inches and 0.20 to 0.28 inch thick, the blows being repeated until the slate breaks. The foot-pounds of work per pound of slate can be calculated from the weight and thickness of the slate and the number of blows.

Toughness or Elasticity. If a slab of slate is fastened between two supports and subjected to pressure it will bend slightly before breaking.

The deflection of certain Pennsylvania slates, when placed on supports 22 inches apart, amounts to 0.27 to 0.313 inch (Merriman).

Density or Specific Gravity. This averages about 2.75, and is affected by the amount of magnetite or pyrite present.

Abrasive Resistance. This is of importance where the slate is used in thick slabs for stair treads. There is no standard method of determining it.

Corrodibility. Slates should resist exposure to an acid atmosphere. They may be exposed to it in two ways, either by moisture or rain water with acid flowing on the upper surface, or by the capillary creeping up of such water between the slate slabs on the roof.

A method of testing this resistance consists in using a solution consisting of 98 parts of water, 1 part of hydrochloric acid and 1 part sulphuric acid. A weighed piece of slate 3 by 4 inches was immersed in this for 120 hours, then dried for 40 hours, weighed, the solution strengthened, and the piece reimmersed for another 120 hours, and weighed again. The losses in tests made by Merriman range from 0 to 2.76 per cent.

Electrical Resistance. If a slate is to be used for electrical switchboards this should be determined.

According to the Electrical Engineers' Standard Handbook the resistance of slate runs about 78,000 megohms per centimeter cube. This is considerably higher than marble, which runs from 435 to 510 megohms per centimeter cube. Slate, however, is not as desirable as marble for switchboards for the reason that it is likely to have veinlets of metallic minerals, which sometimes cause a short circuiting of the current, and it is therefore used much less now than formerly.

Published data of such tests are rare even if they have been made.

Some tests of this character have been carried out on red slate from Slatington, Ark., by Professor W. M. Gladson,[1] whose description follows:

"These pieces of slate were tested in comparison with three pieces of gray slate taken at random from old switch bases in the University electric laboratory. A piece 1 centimeter cube

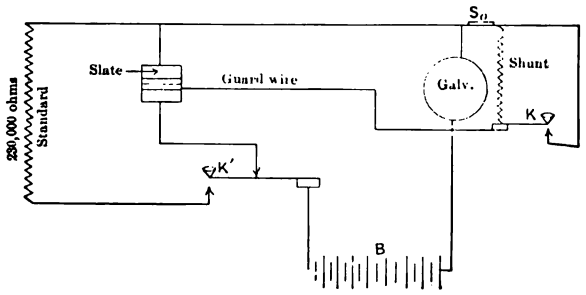

Fig. 4. — Diagram showing electric connections made in testing slate.

was cut from each sample, and these were numbered consecutively from 1 to 9, Nos. 1, 3 and 4, being gray slate. In preparing the cubes metallic particles were found in samples 4 and 6, and Nos. 5 and 6 were so easily split that it was difficult to obtain a centimeter cube.

"The pieces of red slate as received were smooth blocks, 4 by 5 inches by $\frac{5}{8}$ of an inch, neither varnished nor in any way filled. They were red or reddish-brown, were much softer than the gray slate, and split much more readily. All samples tested

[1] U. S. Geol. Surv., Bull. 430 F, p. 57.

were dry and appeared to be seasoned. The method of measuring the resistance of these centimeter cubes was as follows:

"A block of paraffin wax was attached to the center of a glass plate, which in turn was thoroughly insulated from the table by glass strips piled across one another. In the top of the paraffin block an opening was cut 1 centimeter square and about 3 millimeters deep. In the bottom of the cavity thus formed, four copper supports were embedded so that their top surfaces were in the same plane, about 1 millimeter below the top of the paraffin cup. A drop of mercury coming about flush with the copper supports in this cavity formed one terminal for making electric connection to the slate cube. Contact with the opposite face was made by placing a well-amalgamated zinc plate 1 centimeter square on top of the cube. This arrangement insured equal contact with each slate cube under test.

"The galvanometer used was of the D'Arsonval type, and had a working constant of 70,533 millimeters on the scale 1 meter distant through 1 megohm resistance. The electromotive force was furnished by storage cells and was kept constant at 42 volts during the experiment.

"The connections were made as shown in the figure.

"To avoid leakage over the surface of the slate a guard wire was connected as shown. All readings were taken after the deflections became constant; in some cases they did not become so until half an hour after electrification.

"The results of the test are shown in the following table, from which we find the average resistance of all samples to be 1224.2 megohms per cubic centimeter. The average resistance of the three gray samples was 1180, and of the six red-slate samples 1267.8 megohms per cubic centimeter. Each piece tested, except No. 7, shows a different resistance between each pair of opposite parallel faces, which seems to depend on the plane of cleavage. The gray-slate samples show a decidedly higher resistance between faces of cubes perpendicular to cleavage planes, but in individual samples the distribution of resistance would be greatly affected by the presence of foreign conducting particles or seams, which are likely to be present in all slate."

The results of these tests are considerably lower than the figures quoted from the Electrical Engineers' Standard Handbook, and given on page 236.

RESULTS OF TESTS OF ELECTRIC RESISTANCE OF SLATE SAMPLES.

Sample number.	Galvanometer scale deflections.			Resistance.*		
	Perpendicular to cleavage planes.	Parallel to cleavage planes.		Perpendicular to cleavage planes.	Parallel to cleavage planes.	
	D	*D'*	*D''*	*R*	*R'*	*R''*
	mm.	mm.	mm.	Megohms	Megohms	Megohms
1	39.0	40.0	44.0	1808.5	1763.3	1603.0
2	98.0	174.0	625.0	719.7	405.3	67.1
3	171.0	185.0	283.0	414.9	381.2	249.2
4	35.0	94.0	43.0	2015.3	750.4	1640.3
5	104.0	47.7	39.9	678.2	1476.3	1767.1
6	338.9	28.0	88.0	208.1	2519.0	801.5
7	91.0	91.0	48.0	775.0	775.0	1409.4
8	57.0	51.0	27.0	1500.7	1383 0	2012.3
9	45.0	33.0	36.0	1567.4	2137.3	1959.2

* *R*, *R'* and *R''* correspond to the directions *D*, *D'* and *D''*, respectively.

Average of Nos. 1, 3 and 4 (gray slate) 1180.6 megohms per centimeter cube.

Average of Nos. 2, 5, 6, 7, 8 and 9 (red slate) 1267.8 megohms per centimeter cube.

Average of all samples, 1224.2 megohms per centimeter cube.

Tests of Slates. The following tables, taken from the work of Dale and Purdue, include a number of tests that have been made of different kinds of slate.

TESTS ON ARKANSAS SLATE.

Color and quarry.	Modulus of rupture, lbs. per sq. in.		Modulus of elasticity.		Specific gravity.		Per cent absorption, 24 hrs.	
	Max.	Aver.	Max.	Aver.	Max.	Aver.	Max.	Aver.
Red; Southwestern Slate Co.	6,060	4450	4,640,000	3,660,000	2.86	2.86	0.018	0.017
Green; Southwestern Slate Co.	6,840	6620	6,430,000	5,980,000	2.81	2.81	0.008	0.008
Black; M. J. Harrington	9,640	8040	13,420,000	11,090,000	2.70	2.69	0.016	0.014
Reddish brown; M. W. Jones	12,590	9600	19,530,000	16,340,000	2.84	2.84	0.003	0.007
Buff; C. B. Baker.	4,150	3720	6,090,000	5,100,000	2.83	2.82	0.018	0.015

Quoted from report by Purdue, Ark. Geol. Surv.

MERRIMAN'S TESTS ON SLATE.

Color and locality.	Modulus of rupture in pounds per square inch.		Ultimate deflection in inches. Supports 22 inches apart.		Specific gravity.		Per cent absorption in 24 hrs.		Amount in grams abraded by 50 turns of a small grindstone.		Per cent of weight lost in acid solution in 63 hrs.	
	Max.	Aver.	Max.	Aver.	Max.	Aver.	Max.	Aver.	Max.	Aver.	Max.	Aver.
Blue; Chapman Quarries, Pa.	12,490	9460	0.24	0.212	2.78	2.76	0.29	0.23	0.234	0.208	0.560	0.383
Blue; Williams Slate Co., Arvonia, Va.	10,700	9040	0.31	0.227	2.79	2.78	0.20	0.14	0.097	0.06	0.801	0.394
Blue; A. L. Pitts, Arvonia, Va.	11,970	9850	0.25	0.225	2.80	2.79	0.33	0.21	0.159	0.108	0.552	0.323
Blue; Merrill Brownville Slate Co., Brownville, Me.	11,720	9880	0.22	0.20	2.80	2.79	0.18	0.14	0.360	0.265	0.366	0.305
Blue; Monson Cons. Slate Co., Monson, Me.	11,370	9130	0.24	0.20	2.79	2.79	0.20	0.18	0.302	0.256	0.384	0.286
Green; Vermont Unfading Green Slate Co., Fair Haven, Vt.	6,580	6410	0.26	0.22	2 78	2.77	0.30	0.23	0.356	0.341	0.313	0.295
Green; Rising & Nelson Slate Co., W. Pawlet, Vt.	11,040	7250	0.24	0.20	2.75	2.73	0.42	0.32	0.209	0.190	1.067	0.768
Green; Mathews Cons. Slate Co., Boston, Mass.	10,130	8050	0.22	0.19	2.78	2.78	0.40	0.37	0.286	0.226	0.428	0.379
Red; Mathews Cons. Slate Co., Boston, Mass.	11,340	9220	0.27	0.23	2 85	2.84	0.33	0.24	0.304	0.148	0.507	0.373

Price of Slate. The price of slate is usually based on the number of slabs required to cover a square (100 square feet) laid with 3-inch overlap.

The following figures taken from one list give these data for Maine black slates:

Number pieces slate in a square.	Size.	Selected, No. 1.	Extra, No. 2.
686	9× 7	$4.50	.....
515	10× 8	5.00	.....
450	11× 8	5.00	.....
534	12× 6	5.00	.....
458	12× 7	5.50	$4.50
400	12× 8	6.00	5.00
356	12× 9	6.00	5.00
320	12×10	6.00	5.00
291	14× 9	7.00	6.00
277	16× 8	7.75	6.75
185	16×12	7.75	6.75
192	18×10	7.75	6.75
170	20×10	7.75	6.75
127	22×12	7.00	6.00
115	24×12	7.00	6.00

In the Vermont-New York district, the price per square ranges about as follows: No. 1, sea green, $2.25–$4.10; Intermediate, sea green, $3.00–$3.25; No. 1, variegated purple, $2.75–$4.10; No. 1, unfading green, $4.00–$5.25.

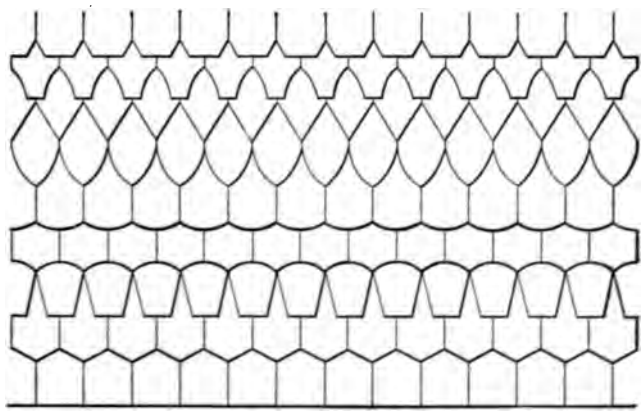

Fig. 5. — Diagram showing some patterns of slate that can be cut on a machine.

The figures given for Penrhyn, N. Y., purple are somewhat as below:

Superficial measure.	Thickness.			
	1 inch or less.	1¼ inches.	1½ inches.	2 inches.
1– 4 square feet	$0.28	$0.32	$0.36	$0.44
4– 8 square feet	0.32	0.36	0.40	0.48
8–12 square feet	0.36	0.40	0.44	0.52
12–15 square feet	0.42	0.46	0.50	0.58
20–25 square feet	0.54	0.58	0.62	0.70
30–35 square feet	0.66	0.70	0.74	0.82

Rubbing, notching, grooving, etc., are charged extra.

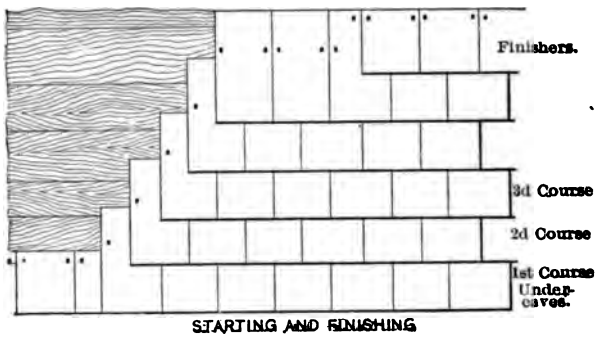

Fig. 6. — Diagram showing section of slate roof with starting and finishing courses.

Quarrying. The waste in slate quarrying is very high, probably never under 60 per cent, and not infrequently as much as 80 per cent. The utilization of the tremendous waste heaps is an unsolved problem.

The salable material taken from the quarry may be used either for roofing purposes or millstock. The latter represents a more massive type, which is cut into slabs for tubs, sinks, table tops, switchboards, blackboards, etc.

Distribution of Slate in the United States. Most of the domestic slate production comes from the eastern states, the quarrying districts forming a broken belt extending from Maine to Georgia. Outside of this there are very few developed areas,

these being in Arkansas and California. The several occurrences are briefly described below.

MAINE.

The chief slate area is located in the central portion of the state and important developments occur around Monson and West Monson, etc. That quarried at Monson is a dark gray color, and the slate obtained at the other localities is similar. The product of the region is used chiefly for roofing purposes, although some quarries turn out millstock as well.

VERMONT.

The most important district lies in Rutland and Bennington counties, and supplies the well-known green and purple slate. This belt passes southwestward into Washington County, N. Y., but the quarries there are of less importance.

The following varieties are obtained:

Sea Green Slate. When freshly quarried this varies from light gray to a slightly greenish gray. The texture is usually fine, and the slate is sometimes slightly magnetitic; it also effervesces slightly. After exposure for a few years it changes to brownish gray, but since the different beds discolor unevenly, the roof may assume a mottled appearance. The slate is used exclusively for roofing purposes.

Unfading Green Slate. This is of greenish gray color, fine texture, and roughish, lustreless cleavage surface. It is magnetitic, and does not effervesce with cold acid.

Several years' exposure produces scarcely any perceptible change. The fissility is inferior to the sea green. The slate is used largely for roofing purposes.

In the northern and western part of the green slate belt, those beds having perfect cleavage are used as millstock and utilized for switchboards and billiard-table tops.

Purple and Variegated. The purple is described as being dark purplish brown; the variegated is like the sea green and the unfading green, but spotted with purplish brown. They are found interbedded with both the sea green and unfading green, and correspond with them in texture and lustre.

The purple of the variegated is said to discolor less than the sea green.

NEW YORK.

Washington County, N. Y., contains a number of slate quarries, the area being a continuation of that in Rutland County, Vermont.

The most important types quarried are the red and green slates, obtained near Granville, Whitehall and Hampton.

The red slate is a reddish brown, and becomes brighter on exposure. It is fine grained and non-fading.

The bright greenish slate is interbedded with the former or sometimes grades into it along the strike. It is likewise unfading. Both effervesce slightly with acid.

NEW JERSEY.

The New Jersey quarries are mostly in a slate of character corresponding to the southeasterly or "hard vein" slates of the region about Chapmans, Pa.

In this stone both the slate and ribbons are harder than those of the soft vein or northwesterly areas, like the Lehigh, Pen Argyl and Bangor, Pa., regions.

That quarried at Newton, N. J., is a hard, bluish black stone.

PENNSYLVANIA.

Aside from the Peach Bottom slate referred to under Maryland, an important area is found in Northampton and Lehigh counties of eastern Pennsylvania, and forms a large source of supply, the two chief centers being Bangor and Slatington.

In the broad strip there are two belts of commercial slate. The more northern of the two is known as the *soft vein*, and consists of belts of relatively soft slate, which is thick enough between the ribbons to furnish large slabs for millstock or roofing slate.

The more southern belt or *hard vein*, consists of small beds of harder slate, separated by small ribbons not coarse enough to interfere with their use either as millstock or roofing slate.

● Productive districts
■ Prospective deposits

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The quarries at Bangor, East Bangor, Pen Argyl, Danielsville, Slatington and Slatedale are in the soft vein, while Belfast and Chapman are in the hard vein.

The slates of eastern Pennsylvania are mostly a very dark bluish gray, or grayish black. They are used chiefly for roofing purposes, but some of the quarries produce considerable millstock.

MARYLAND.

An important slate-producing district known as the Peach Bottom slate area lies on the border of Maryland and Pennsylvania, but the chief production comes from the former state, the quarries being located near Cardiff.

The slate is said to be tough, fine grained and moderately smooth in texture. It is also less fissile than many of the slates quarried to the northeast and, according to Merrill, will yield, as a rule, only six slabs to the inch, while those of Monson, Me., and Slatington, Pa., yield twice that number. Its greater strength and elasticity are thought to be due to the fact that it is more metamorphosed than most slates. The color is good and the weathering qualities are regarded as excellent.

WEST VIRGINIA.

A black slate of slightly brownish hue, lustreless character and roughish cleavage is quarried at Martinsburg.

VIRGINIA.

A dark gray slate, which is of durable color and good strength, is produced at Arvonia.

GEORGIA.

Roofing slate is quarried near the town of Rockmart. It is black in color and splits readily into slabs of moderate thickness.

ARKANSAS.

Slate deposits are known in west central Arkansas, in a belt about 100 miles long lying west of Little Rock. During recent years the best developments have been in Polk and Montgomery counties.

The following grades are noted: (1) Black slate from Mena; (2) Dark reddish slate, somewhat darker than the New York red slate; (3) Reddish slate; (4) Greenish gray slate, resembling the sea green of Vermont; (5) Light greenish slate; (6) Dark and light gray slate.

The slate has been quarried for roofing purposes and switchboards, but does not seem altogether satisfactory for the first, on account of a tendency to disintegrate.

CALIFORNIA.

One important slate area is known in the state in Eldorado County. The material is a dense, deep black slate, which splits finely and regularly, with a smooth, glistening surface. It makes good roofing material, but the frequency of the ribbons and pyrite nodules interferes with its use as millstock.

The California slates are of considerable commercial importance, as they are the sole source of supply on the Pacific Coast. They are also of interest scientifically, because they have been derived by the metamorphism of igneous rocks instead of the usual sedimentary ones.

CHAPTER VII.

SERPENTINE.

PURE serpentine is a hydrous silicate of magnesia, but masses of serpentine rock are rarely pure and usually contain varying quantities of such impurities as iron oxides, pyrite, hornblende, pyroxene and carbonates of lime and magnesia.

Many serpentines are green or greenish yellow, while others, especially the more impure ones, are various shades of black, red or brown.

Spotted green and white varieties are called *ophiolite* or *ophicalcite*. In these the white ground is calcite, while the green spots are serpentine, which may contain a core of some other silicate mineral.

Verde antique is a somewhat general name applied to green serpentinous marbles.

Serpentine sometimes occurs in sufficiently massive character to be used in structural or decorative work, but owing to the frequent and irregular joints found in nearly all serpentine quarries it is difficult to obtain any slabs except small ones.

As a general rule it is extremely unsafe to use serpentine for exterior work in a severe climate, but for interior decoration its softness, beautiful color, and high polish make it a very desirable stone.

The objection to it for exterior application is that it weathers irregularly, cracks, loses its lustre and fades in spots. Indeed, it is one of the most defective stones to use outdoors.

Distribution of Serpentine in the United States. There are comparatively few occurrences of this rock in suitable quantities for quarrying, moreover only a small number of these are worked, and even then not continuously. Only the more important ones are mentioned.

Massachusetts. Some serpentine has been quarried in the Hoosac Mountain Range. According to Crosby (quoted by Merrill), the quarry affords dark green serpentine, serpentinized gray marble and massive, spangled serpentinized marble. Little use appears to have been made of this stone.

Vermont. Near Roxbury there is found a serpentine which G. P. Merrill has characterized as "one of the most beautiful of all our serpentines and the best adapted for all kinds of interior decorative work. The colors are deep, bright green, traversed by a coarse network of white veins." The stone also takes a beautiful polish.

New York. Attempts have been made to quarry an ophicalcite found near Moriah and Port Henry in Essex County, N. Y. The stone is rather decorative and takes a good polish, but the reasons which have apparently prevented its extended use are difficulty of obtaining large blocks and presence of pyrite.

New Jersey. Serpentine for decorative work has been quarried north of Phillipsburg on the Delaware River. The stone is of a dark green color, and also shows a mottled mixture of dark and light, occasionally sprinkled with grayish, pinkish or flesh-colored dolomite crystals, and sometimes veined with streaks or seams of pure white compact to fibrous calcite, in which are embedded fibers of asbestos. Much of this rock furnishes beautiful polished slabs.

Pennsylvania. A handsome ornamental serpentine, known as *verdolite*, has been quarried near Easton, but while the stone is very beautiful the blocks are of very irregular size.

This serpentine has been used recently for interior work in the Episcopal Cathedral of St. John the Divine in New York City. The parts are the floor border (in part) in the choir; choir steps; ambulatory; bands and moldings in the interior.

Several serpentine areas are found in southeastern Pennsylvania, but none are suitable for monumental work. Quarries have been operated in the town of West Chester, Chester County, and have in the past supplied not a little stone for building purposes. It has been used for some of the University of Pennsylvania buildings and some Philadelphia churches.

PLATE XLIII. — Serpentine Pedestal, Charlottesville, Va. This stone has been attacked to an appreciable extent by the weathering agents.
(Photo by H. Ries.)

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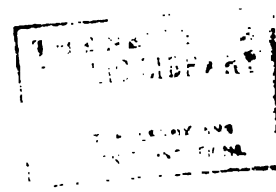
PLATE XLIV. — Serpentine from Roxbury, Vt.



Maryland. Serpentine has been quarried sporadically in this state for a number of years, and the quarries on Broad Creek in eastern Hartford County have supplied some good stone. The stone is compact, of dark green color, and polishes well. It makes an excellent decorative stone for interior work but has been little used.

Georgia. A handsome serpentine has been worked at the Verde Antique Marble quarry near Holly Springs, Cherokee County.

The stone is described as massive, with a slight tendency towards schistosity, but is not uniform in structure or mineral composition. It shows beautiful venations. The stone has not been quarried steadily and is adapted to interior work.

Examples. — Corridors of Prudential Building and Smoking Room at Terminal Station, Atlanta, Ga.

California. Serpentine is not an uncommon rock in this state, but the production for structural and decorative work is almost negligible. The main supply seems to have come from quarries sixteen miles northeast of Victorville. It varies from light yellow-green to dark green, and is said to have been used for interior decoration in Los Angeles and San Francisco.

Washington. Serpentine has been quarried in Stevens County, where it is associated with marble. It is of different shades of green, with white carbonate minerals scattered through it. The types quarried include Royal Washington, Landscape Green, and Athenian Green.

ONYX MARBLES.

The term *onyx marble* is applied to two types of calcareous rock having a crystalline texture.

One of these is a chemical deposit formed in limestone caverns. As surface waters seep through limestones they take some lime carbonate in solution, which they deposit later on the roof or floor of the caverns into which they find their way.

The other type of onyx marble is a travertine or hot-spring deposit, precipitated on the surface.

In both cases the lime carbonate precipitated from the water is built up, layer upon layer, but the deposits are rarely of great

thickness, and far less extensive than those of the ordinary limestones and marbles.

Onyx marbles usually show a characteristic banding, which is due to their mode of accumulation, and while successive layers may vary slightly in their color and texture, still in good stones there is little tendency for the rock to separate along these planes.

The decorative beauty of the stone is due to its translucency, to the cloudings produced chiefly by iron oxide, and to the fine veins which extend through the rock in different directions.

These veins are sometimes emphasized by the addition of coloring matter which has filtered in along the fractures in the rock.

The colorings shown by onyx marbles include different shades of green, red-brown, red, yellow and amber.

The cave onyx is usually less translucent and coarser grained than the travertine onyx.

There are comparatively few localities which supply onyx marbles of commercial value.

Deposits are known to occur in Arizona and California, but they have been worked only to a very small extent, although some of them possess considerable beauty.

One of the main sources of supply has been the region southeast of Pueblo, Mexico, but the quarries are small, there is much waste in quarrying and it is difficult to obtain large slabs.

Highly ornamental onyx of white, rose, red, yellow and green colors is obtained from Algeria.

Persia, Italy, France, Egypt and Argentina have all supplied some handsome stone of this class.

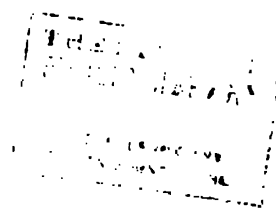
Onyx marbles are quite frequently used for wainscoting and paneling, as well as for table tops and counters. Some are also employed for ornamental purposes.

When used in slab form, little attention is paid to matching the patterns of the different slabs.

In rare cases onyx marbles are set as floor tiling and stair treads, but this is a serious error, as the stone is not sufficiently strong or durable for this purpose.

PART II.

CLAY PRODUCTS.



CHAPTER VIII.

PROPERTIES OF CLAY.[1]

THE clay products in which the architect is especially interested are those which are used chiefly for structural and decorative work.

This, then, would include building brick, either common or front, enameled brick, fireproofing, architectural terra-cotta, wall, floor and roofing tiles, sewer-pipe and sanitary ware.

As regards the finished product, the architect should not only have some knowledge of the qualities and applications of the ware itself, but it is also important that he should possess some information regarding the raw materials employed and the method of manufacture, since these more or less directly affect the character of the finished article.

Before taking up the different classes of burned clay wares, it may be desirable, therefore, to give a brief discussion of the raw materials widely employed in their production.

The properties of clay may be divided into two groups, physical and chemical, the former being the more important. They determine to a large extent the use to which the clay can be put, and may even, in some cases, influence the behavior of the clay in manufacturing, as well as the character of the finished product.

PHYSICAL PROPERTIES.

These include, among others, plasticity, air and fire shrinkage, tensile strength, and fusibility.

Plasticity. This may be defined as the property which clay possesses of forming a plastic mass when mixed with water, thus permitting it to be molded into any desired shape, which it retains when dry. It is an exceedingly important property, the

[1] For a more detailed discussion of this subject see Ries, "Clays, their Occurrence, Properties and Uses," Wiley and Sons.

more so if the clay is to be modeled into complex designs, such as are often called for in the production of terra-cotta wares. Clays vary from exceedingly plastic or " fat " ones to those of low plasticity, which are termed lean. In order to get a mass of the proper plasticity the manufacturer often mixes two clays of different character. Highly plastic clays often show a high shrinkage, while in lean ones the reverse is usually true. The clay worker, therefore, sometimes adds sand to the clay, in order to reduce the shrinkage and sometimes also the plasticity. If too much sand is added it may make the product porous and weak, especially if it is not hard burned. An excellent example of this is often seen at some small brick yards, where the brick-maker either uses a clay that is very sandy, or else adds too much sand to a plastic one. One result of this is that it makes the clay work more easily, but yields an open, soft brick.

Shrinkage. Two kinds of shrinkage are recognized, i.e., air shrinkage and fire shrinkage. The former takes place while the clay is drying after being molded, the latter occurs during firing. Both are variable, and while a small amount at least is desirable, in order to permit the clay particles to draw together to a tight body, an excess may lead to serious results. Excessive air or fire shrinkage often causes cracking or warping of the clay during drying and burning respectively, and is to be avoided.

The clay worker should therefore adjust his mixture so as to have the proper amount of shrinkage, and where the finished ware must have certain dimensions this is often adjusted with considerable care.

A word more should be said about the fire shrinkage. This usually begins during the burning process at a temperature of redness and increases with the temperature of burning up to a point at which the clay is vitrified, beyond which the material swells. The fire shrinkage does not proceed at the same rate in all clays, nor do they all reach their maximum shrinkage at the same heat. Moreover, some clays, notably the sandy and calcareous ones, may even expand slightly at a dull red heat.

In the manufacture of most clay products an average total shrinkage of about eight or nine per cent is commonly desired.

Tensile Strength. Tensile strength is the resistance which a mass of air-dried clay offers to rupture. It is regarded by many as an important property and helps the clay to withstand the shocks of handling in its air-dried condition. It bears no necessary relation to the strength of the burned ware.

The transverse strength of the air-dried clay stands in direct relation to the tensile strength.

Fusibility. This is one of the most important properties of clay. When subjected to a rising temperature, clays, unlike metals, soften slowly, and hence fusion takes place gradually. In fusing, the clay passes through three stages, termed respectively, incipient fusion, vitrification and viscosity. It is somewhat difficult at times to exactly locate each of these, so gradual is the change, but the recognition of them is of considerable practical importance. They might be defined somewhat as follows: —

Incipient fusion is the point at which the clay grains or cement have become sufficiently soft, in part at least, to make the mass stick together. The clay body is still very porous and can be scratched with a knife. It is not, therefore, "steel hard."

Vitrification represents a degree of heating sufficient to soften the grains so that extensive fluxing has taken place, and the particles have settled together, forming a tight, solid, practically non-absorbent mass. The clay body still holds its shape, however.

Viscosity is the stage at which a clay has become sufficiently heated to so soften that it no longer holds its shape.

Comparison of different clays shows us:

(1) That the temperature of incipient fusion is not the same in all, and (2) That the three stages are not equi-spaced.

Thus in calcareous clays the temperature interval between the extreme points (incipient fusion and viscosity) is very small, while in other clays it may be quite large.

The practical bearing of these facts is this: In burning a kiln full of ware, it is impossible to control the temperature within a few degrees, so that if the ware is to be vitrified, we must have a sufficiently large temperature interval between

vitrification and viscosity, to permit reaching the former point without danger of running on to the latter, and melting down the entire contents of the kiln.

The degree of vitrification is indicated by the absorption. Common brick, which are usually burned to incipient fusion or a little beyond, show an absorption of from ten to twenty-five per cent, while paving brick, which are vitrified or nearly so, have from one to five or six per cent absorption.

CHEMICAL PROPERTIES.

The chemical composition of a clay influences the color in burning and the fusibility, but is not the only factor affecting these results; for this reason the use of the chemical analysis for purposes of interpretation is somewhat restricted.

The substances usually determined in the chemical analysis are silica (SiO_2), alumina (Al_2O_3), ferric oxide (Fe_2O_3), lime (CaO), magnesia (MgO), alkalies (Na_2O,K_2O) and water of combination (H_2O). Others which are rarely determined are carbon (C), sulphur trioxide (SO_3) and carbon dioxide (CO_2).

The effects of these are somewhat as follows: Iron oxide if evenly distributed tends to color the clay some shade of red, brown or buff under normal conditions of burning. Thus a clay free from iron oxide usually burns white, one with a small percentage burns buff and one with considerable iron oxide burns red or brown.

Lime, if evenly distributed through the clay and present in great excess over the iron oxide, counteracts it and gives a buff or cream coloration, unless the ware is underburned. The well-known Milwaukee cream brick are an example of this. The Philadelphia red brick, so much in fashion in former years, owe their color to a liberal quantity of iron oxide in the clay. Brick manufacturers sometimes improve the color of soft-mud brick by adding some hematite (iron oxide) to the molding sand.

If present in lumps the lime may slake and split the brick (Plate XLIX, Fig. 1). For this reason any lime pebbles in the clay should either be eliminated or rendered harmless by crushing, since in the burning of the brick they are converted into

quicklime. An attempt is sometimes made to prevent the trouble by quenching the bricks with water when they are taken from the kiln.

Iron oxide, lime, magnesia and alkalies are spoken of collectively as fluxes and lower the fusibility of the clay, so that, other things being equal, one with a high total percentage of these will fuse at a lower temperature than one containing a small quantity, provided the fluxes are evenly distributed through the clay and the latter is fine grained.

Most brick clays burn red because of the iron oxide which they contain, and also fuse at a comparatively low heat, while fire clays burn buff because of their low iron contents, and also withstand a high degree of heat, on account of their low percentage of fluxes.

We see then that a buff or cream brick can be made either from a very calcareous clay, or from one which is low in both lime and iron oxide.

The effect of carbon is this: Carbon, in order to burn, requires oxygen. This it may obtain from the kiln atmosphere, or, failing this, from ferric oxide present in the clay, as a result of which the ferric oxide becomes reduced to ferrous oxide. The latter, however, combines readily with the silica in the clay, forming an easily fusible ferrous silicate. Now, as a result of this fusion, which begins first in the outer portion of the brick, a tight, vitrified zone forms around the center which still contains the carbon. The carbon in this inner zone may continue to burn and liberate gases, which, being unable to escape through the outer fused zone, exert sufficient pressure to bloat the brick. Or, in any event, if burning does not go far enough to cause bloating, there may be a black core.

Sulphur is present in many clays, commonly in the form of pyrite, a sulphide of iron, whose yellow metallic grains and lumps are often easily noticed.

In burning, the sulphur is driven off in gaseous form, as sulphurous or sulphuric acid gas, but does not pass off until after the chemically combined water and carbon. If allowed to remain in the clay it is a common cause of premature swelling and black coring.

Analyses of Clay. The following table will serve to show the variation in composition of clay. For purposes of manufacture these are of comparatively little value, as they throw little light on the physical behavior of the material. The interpretations which can be made from these are to be regarded as of only approximate character.

ANALYSES SHOWING VARIATION IN COMPOSITION OF CLAYS.

	I.	II.	III.	IV.	V.	VI.
Silica (SiO_2)	45.70	56.2	66.01	88.71	59.03	47.92
Alumina (Al_2O_3)	40.61	23.7	18.82	4.88	11.19	14.40
Ferric Oxide (Fe_2O_3)	1.39	1.5	6.33	2.00	2.77	3.60
Lime (CaO)	0.45	0.6	0.55	0.30	12.16	12.30
Magnesia (MgO)	0.09	1.5	1.88	0.97	0.80	1.08
Soda (Na_2O)	.....	2.2	0.08	tr.	0.18	1.50
Potash (K_2O)	2.82	1.4	.16	tr.	tr.	1.20
Titanic acid (TiO_2)	.....	1.0	0.95	0.90	1.05	1.22
Water (H_2O)	8.98	11.1	4.80	2.28	2.10	4.85
Carbon dioxide (CO_2)	.....	.....	.....	.....	9.60	9.50
Sulphur trioxide (SO_3)	.....	.....	.....	.....	.....	1.44
Organic matter	.....	.....	.....	.....	.....	1.34
Moisture	.35	.....	.....	.....	.....	.....
Total	100.39	99.8	99.58	100.04	98.88	100.35

I. A white burning clay.
II. Buff burning fire clay.
III. Red burning brick clay.
IV. Sandy brick clay.
V. Calcareous, buff burning brick clay.
VI. A red burning shale. Develops black core if burned too fast.

CHAPTER IX.

BUILDING BRICKS.

Kinds of Brick. Under this heading are included common brick, face or pressed brick, enameled brick and glazed brick.

Common brick include all those used for ordinary structural work and are employed usually for side and rear walls of buildings or, indeed, for any portion of the structure where appearance is of minor importance, although for reasons of economy or otherwise they are sometimes used for front walls.

They are often made without much regard to color, smoothness of surface, or sharpness of edges.

Face, front or pressed brick include those made with greater care and usually from better grades of clay, much consideration being given to their uniformity of color, even surface and straightness of outline. In recent years, however, there has been a departure from some of these surface characters.

Enameled brick include those which have a coating of enamel, either bright or dull, on one and sometimes two surfaces.

Glazed brick differ from enameled brick in being coated with a transparent glaze instead of an opaque enamel. They are more used in Europe than in the United States.

The following terms are used more or less in the trade.

Air Brick. Hollow or pierced brick built into wall to allow passage of air.

Arch Brick. This term may be applied to either wedge-shaped brick used for the voussoir of an arch, or to brick taken from the arches of a kiln. The latter type are hard burned and sometimes even rough and twisted by excessive heating.

Ashlar Brick. A term often applied to certain brick, whose one edge is rough chiseled to resemble rock-faced stone.

Clinker Brick. A very hard burned brick.

Compass Brick. Same as first meaning for arch brick.

Dutch Brick. Defined by Sturgis as a hard, light colored, paving brick, used in England. Originally made in Holland.

Fire Brick. One that stands a high degree of heat.

Flashed Brick. This includes those pressed brick which have had their edges darkened by special treatment in firing. This color is superficial and may range from a light gold to a rich reddish brown.

Furring Brick. Hollow brick for lining or furring inside of wall. Usually common brick size, with surface grooved to take plaster.

Hollow Brick. Brick molded with hollow spaces and used for partitions, etc.

Norman Tile. Brick having the dimensions 12 by $2\frac{1}{4}$ to $2\frac{1}{2}$ by 4 inches.

Ornamental Brick. Those with surface ornamented with a relief design. They are not necessarily of conventional shape, but may be of square outline. Some would include under this heading all brick which are not of plain rectangular character. This would then include angle brick, bullnose brick, beaded brick, cover brick, and all shapes which have an ornamental surface pattern.

Pale Brick. Underburned brick. Usually of lighter color than normally burned ones in same kiln. They are often porous and soft, and used mostly for backing.

Paving Brick. One of low absorption and good hardness and abrasive resistance, which is used for paving purposes.

Pompeiian Brick. These are of the same size as Roman tile (q. v.), but are a medium dark shade of flashed brick, with a brownish body covered with iron spots. The two terms Roman and Pompeiian have been very loosely used.

Pressed Brick. A loosely used term, applied to smooth-faced and smooth-edged brick, made either by the dry press or by the softer mud processes and then repressed.

Rock-face Brick. Those with surface chiseled to imitate cut stone.

Roman Tile. Brick, usually either dry pressed or stiff-mud repressed, and 12 by $1\frac{1}{2}$ by 4 inches in size.

PLATE XLV, Fig. 1. — Ornamental, dry-pressed brick.

PLATE XLV, Fig. 2. — Tapestry brick. (Photo copyrighted by J. Parker Fiske.)

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Salmon Brick. Soft, imperfectly burned brick. So called on account of their color. Same as pale brick.

Sewer Brick. A general term applied to those common brick which are burned so hard as to be practically non-absorbent. They are, therefore, adapted for use as sewer linings.

Slop Brick. A name sometimes applied to those made by the soft-mud process.

Stock Brick. A term sometimes applied to the better selected bricks from a kiln.

Tapestry Brick. These are brick made by the stiff-mud process, and having their surfaces roughened by cutting a thin slice off the brick by a wire. They are much used nowadays for fronts.

RAW MATERIALS USED FOR BUILDING BRICK.

It may be stated, as a general proposition, that the higher grades of brick are usually made of the better grades of clay.

At some yards or in some districts, the same clay may be used for both common and pressed brick, in which case the latter are manufactured with greater care.

Common Brick. The clays and shales used for common brick are usually of a low grade, and in most cases red-burning. Calcareous clays giving a cream-colored product are much employed in some districts, as, for example, in Wisconsin, Michigan and Illinois, but this is largely because of necessity and not choice. The main requisites are that they shall mold easily and burn hard at as low a temperature as possible, with a minimum loss from cracking and warping.

Unfortunately but little care is often used in the selection of clay for common brick, and the product shows it.

Lime pebbles, if present, should be either crushed or screened out, otherwise they are sure to cause cracking and bursting after burning.

Pressed Brick. Pressed brick are now often made from a higher grade of clay. The kinds employed fall mostly into one of three groups, namely: (1) red-burning clays; (2) white-burning clays; (3) buff-burning clays, usually of at least semi-refractory character.

The physical requirements of a pressed-brick clay are: (1) uniformity of color in burning, (2) freedom from warping or splitting, (3) absence of soluble salts, and (4) sufficient hardness and low absorption after burning. The first requisite is perhaps not as rigidly adhered to as formerly.

Red-burning clays were formerly much used, and the Philadelphia red brick are well known to many architects. Cream-colored brick, made of calcareous clays, such as the Milwaukee brick, were also widely employed at one time. But in recent years buff-burning, semi-refractory and refractory clays have found wide-spread favor among pressed-brick manufacturers, partly on account of their color and partly because coloring materials can be effectively added to them. Manganese in powdered or granular form is the coloring agent most commonly employed.

Enameled Brick. The clays used for these are similar to those employed in the manufacture of buff pressed brick. The enamel is an artificial mixture which must conform to the clay body to avoid cracking or scaling off of the coat. It is in turn covered by a glaze.

METHODS OF BRICK MANUFACTURE.

These may be briefly taken up in order to point out their influence on the character of the products and some other details of importance to the architect or engineer.

The methods employed in the manufacture of common and pressed brick are usually similar, the differences being chiefly in the selection of material, degree of preparation and amount of care taken in burning.

The manufacture of brick may be separated into the following steps: preparation, molding, drying and burning.

Preparation. This stage might be divided into two parts, viz., (1) crushing and (2) tempering or mixing. Hard shales and very tough clays usually have to be broken up by proper machinery, in order to facilitate the admixture of water to them if they are to be used wet, or if to be pressed in a dry condition they can be pulverized and then screened. The coarse texture of some dry-press brick is due to insufficient grinding.

If soft, the clay, mixture of clays, or clay and sand can be charged right into the tempering machine.

In some cases weathering of the clay precedes the mixing, the crushing being left out. This exposure to the weather may often benefit the clay and cure some faults; in other cases it is of injury.

The tempering or mixing is an important stage in the process and the more thoroughly done the greater the homogeneity of the product. At many small yards, and even some large ones, as in the Hudson River district, the raw material is simply dumped into a pit, water poured on and the mass allowed to soak over night, or at others the clays are put into a circular pit (ring pit) in which a wheel revolves following a spiral path, thus cutting and mixing the clay. In more modern works the raw material, however, is mixed in a pug mill, consisting of a semi-cylindrical trough in which there revolves a horizontal shaft set with knife blades. The clay, being fed into this with water, becomes disintegrated and mixed.

Wet pans, consisting of heavy rolls set in a revolving pan, perform a similar function.

In all tempering it is essential to mix and disintegrate the clay, for if this is not done lumps may be left, which not only tend to cause cracking in drying and burning, but may also reduce the transverse strength. Pebbles left in the clay give similar trouble.

Since pug mills are continuous in their action, a greater quantity of clay can be handled per machine in a given time than in the case of some of the other machines used.

Molding. Brick are molded by one of four methods, namely: soft mud, stiff mud, dry press and semi-dry press. In reality there is not so much difference between the last two.

Soft-mud Process. In this method the clay, or mixture of clays, is mixed with water to the consistency of a soft mud or paste and pressed into wooden molds. Since, however, the wet clay is sticky and likely to adhere to a wooden surface, the molds are usually sanded each time before being filled, in order to facilitate the delivery[1] of the brick. Soft-mud brick are molded

[1] At some hand-power yards, water is used instead of sand.

either by hand or in a machine, the latter being operated by horse or steam power.

Fig. 7. — Soft-mud brick machine.

The soft-mud machine (Fig. 7), consists essentially of an upright box of wood or iron, in which there revolves a vertical shaft bearing several blades, while attached to the bottom of the shaft is a curved arm that forces the clay into the press box. The molds after being sanded are shoved underneath the machine from the side and move forward to a position underneath the press box. As the mold reaches this position the plunger descends and forces the soft clay into the compartments of the mold. This filled mold box is then pushed forward automatically upon the delivery table while an empty one moves forward to take its place. As soon as the mold is delivered, its upper surface is "struck" off by means of an iron scraper. The mold is then emptied onto pallets on which the brick are carried to the drying racks, or the mold is taken to the drying floor where the brick are dumped out.

A soft-mud machine operated by steam power will commonly turn out about 25,000 brick per day. If molded by hand from 2500 to 3000 are usually made.

Soft-mud brick can be easily recognized by their external appearance (Plate XLVI, Fig. 1), for on account of the method of molding employed, they show five sanded surfaces, while the sixth surface will be somewhat rough due to excess of clay being wiped off even with the top of the mold.

The process is adapted to a wider range of clays than any of the others and possesses the advantage of producing not only a brick of very homogeneous structure but one that, if properly burned, is rarely affected by frost action.

Those which are hand molded are often more porous than the machine-molded ones, but this may be partly due to the character of the raw materials employed and handling of the burn-

PLATE XLVI, Fig. 1. — Common red soft-mud brick. The roughness of upper surface is due to striking off excess of clay in mold. The other two exposed surfaces are sanded ones.

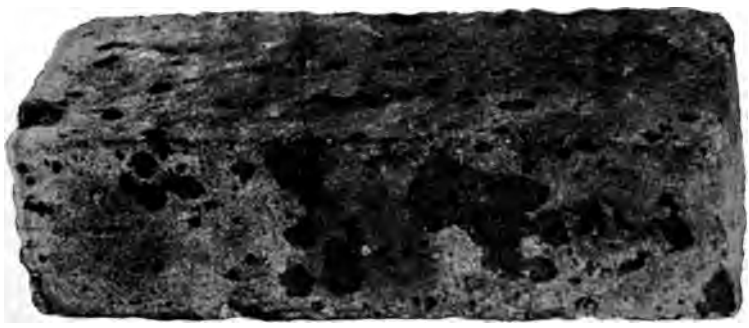

PLATE XLVI, Fig. 2. — A common soft-mud brick. The iron oxide was not evenly distributed in the clay, but was present in lumps and hence caused the blotches.

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ing. Soft-mud brick, unless repressed, lack very sharp corners and straight edges. Their fracture may also show more pebbly particles than that of brick formed by the other two processes.

On a later page will be found the tests of a number of soft-mud brick.

Stiff-mud process. In this method the clay is mixed with sufficient water to make a stiff plastic mass, and the principle of the process consists in taking the clay thus prepared and forcing it through a die in the form of a rectangular bar, which is then cut up into bricks.

The form of machine (Fig. 8) most commonly employed is known as the auger machine, and consists of a cylinder closed at one end, except for a feed hopper on top, but at the other end tapering off to a rectangular die whose cross section is the same as either the end or the largest side of a brick. Within this cylinder, which is set in a horizontal position, there is a shaft, carrying blades similar to those of a pug mill, but at the end of the shaft nearest the die there is a tapering screw. The die is properly lubricated to prevent sticking of the clay.

The tempered clay is charged into the cylinder at the end farthest from the die, is mixed by the blades on the revolving shaft, and at the same time moved forward until seized by the screw and forced through the die. This forcing of the clay through the opening, which is small as compared with the full cross section of the cylinder, results in a marked compression of the clay, and there is also some friction between the sides of the bar and the interior of the die, causing the center of the stream of clay to move faster than the outer portion. If the friction between clay and die is greater than coherence between clay particles, a tearing of the clay, especially on the edges of the bar, results, producing serrations like the teeth of a saw. This may not seriously weaken the brick, however. The twisting action of the screw at the end of the shaft also produces a spirally laminated structure (Plate XLVII) in some clays, which is often most pronounced in very plastic clays.

As the bar of clay issues from the machine it is received on the cutting table, where it is cut up into bricks by wires, fastened either in parallel arrangement on a frame, or fastened to the forked ends of spokes of a wheel. As the wires make a somewhat rasping cut, the cut surfaces are always recognizable on a stiff-mud brick.

Brick made in auger machines are either end cut or side cut, depending on whether the area of the cross section of the bar of clay corresponds to the end or side of a brick, and consequently the mouth of the die varies in size and shape.

The stiff-mud process, while one of high capacity, — 60,000 or even 100,000 brick per day being produced without difficulty, — is not adapted to all kinds of clays, those of medium plasticity giving perhaps the best results, so that defective brick are sometimes the fault of the process and not of the clay.

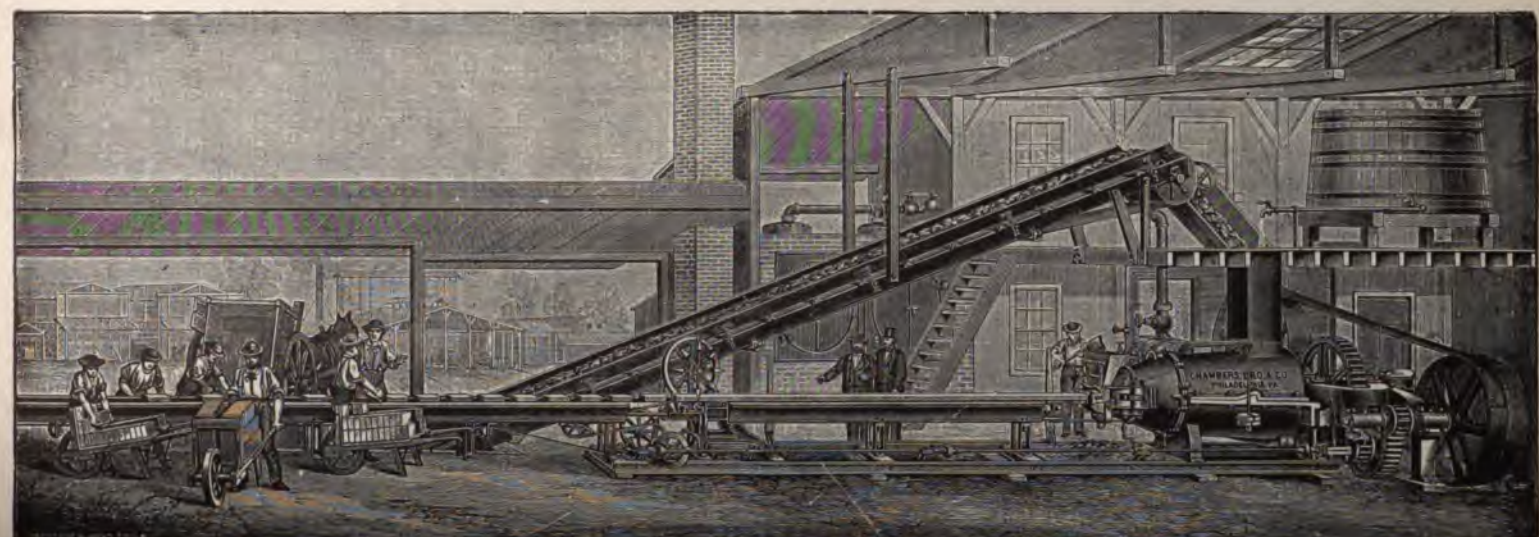

Fig. 8. — Manufacture of brick by stiff-mud process.

Plate XLVII. — Section of stiff-mud brick showing laminations.

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PLATE XLVIII. — Dry-press brick machine. (After Ries, N. Y. State Museum, Bull. 35, 1900.)

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A stiff-mud brick can be easily recognized by the four smooth surfaces and the two cut faces, which show the tearing action of the cutting wires. The laminations are to be looked for on these last-mentioned surfaces. In some brick they are so pronounced as to cause the different shells to separate somewhat in burning.

Dry-press and Semi-dry-press Process. This process is commonly used for the production of front brick, but in some states is extensively employed even for common brick manufacture. The clay is first allowed to dry out under sheds until it has not more than 12 or 15 per cent moisture, and then disintegrated in suitable machines, after which it is screened and the screenings conducted into the hopper of the press. The process consists essentially in pressing this partly dry, pulverized clay in steel molds.

The molding machine (Plate XLVIII) consists of a steel frame of varying height and heaviness, with a delivery table about three feet above the ground, and a press box sunk into the rear of it. The charger is connected with the clay hopper by means of a canvas tube and forms a framework which slides back and forth over the molds. It is filled on the backward stroke, and on its forward stroke lets the clay fall into the mold box. As the charger recedes to be refilled, a plunger descends, pressing the clay into the mold; but at the same time the bottom of the mold, which is movable, rises slightly, and the clay is subjected to greater pressure, which may be repeated after a moment's interval. The plunger then rises, while the bottom of the mold also ascends, pushing the freshly molded brick to the level of the delivery table. They are then shoved forward as the charger advances to refill the molds.

In order to release at least some of the compressed air imprisoned in the clay, the dies are provided with air vents.

The advantages claimed for the dry-press process are that in one operation it produces a brick with sharp edges and smooth faces. Air drying is eliminated, but there is considerable moisture to be driven off in the kiln during the early stages of burning. Dry-press brick, unless well vitrified, often show a granular structure because the clay grains do not amalgamate as they could if the clay were mixed wet, and if, because of hardness, the clay does not break down easily, these granulations may be very noticeable. Dry-pressed brick, if hard-burned may be just as strong as others, but, if not hard burned, they frequently show a much higher absorption than if the clay had

been molded wet. The capacity of a dry-press machine is about the same as that of a soft-mud one.

Repressing. Many soft-mud and stiff-mud brick that are to be used for fronts are improved in appearance by repressing. The process consists in putting them in a machine shortly after molding, in which they receive a second pressing. The main object of this is to straighten the edges and smoothen the surface, and in many cases some design is imprinted in the surface of the brick. The brick are usually slightly smaller after this treatment. The pressure which the brick get, together with the use of some lubricant and the slipping in and out of the mold, polishes the surface so at times as to form a tough exterior skin which strengthens their resistance to disintegrating influences. Repressing may also make the brick denser and even stronger, as shown by the following tests which were made on some hand-molded, soft-mud, New Jersey samples.

Crushing strength.	I. Before repressing.	II. After repressing.
Crushing strength, pounds per square inch...	3107	4.304
Transverse strength modulus of rupture.....	440	613
Absorption.....	12.09%	9.75%

Drying. Bricks made by either the stiff-mud or soft-mud process have to be freed from most of their water before they can be burned.

For the purpose of this discussion it is not necessary to go into a detailed description of the methods of drying, but certain features of interest or value to the architect may be pointed out.

At many common brickyards the product is dried on floors exposed to the sun or air. This process in no way detracts from the quality of the product, but can be carried on only during those months when the temperature is above freezing. Moreover, a yard employing this method is of limited capacity unless a large floor space is available. During rainstorms the surface of the brick becomes roughened by the beating of the raindrops, and such washed brick are not as a rule salable, although if

PLATE XLIX, Fig. 1.—Common red soft-mud brick which has been split by air slaking of calcined lime pebbles; the two white spots are the pebbles.

PLATE XLIX, Fig. 2. — Repressed brick. The rounded edges and corners as well as the grooves were produced in the repressing.

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burned they do not lack in strength. The practice of drying the brick on racks under sheds is an improvement. At many common brickyards, and all those where front brick are manufactured, artificial heat is used for drying, the brick being stacked on cars and run into tunnels, which are heated by appropriate means. This system permits the operation of the plant throughout the year and possesses an advantage over the open-air system. The drying, however, is not necessarily more rapid. Indeed, some clays have to be tunnel dried with great care to prevent cracking of the product.

Burning. In this stage of the manufacture, the bricks are converted into their permanent durable form, the process being carried out in kilns of one type or another.

The temperature required for burning brick will vary with the clay and density, degree of hardness and color desired, the same clay yielding different results when fired at different temperatures. Common brick are usually fired at a red heat, and not always even a bright red, while pressed brick, especially if made of fire clay, are burned at a much higher temperature.[1] Still, even in the same kiln, we oftentimes find a difference in temperature in different parts, and this alone may produce variations in the character of the product in any lot.

The kilns used might be divided into two groups, viz., temporary and permanent, and the latter still further into intermittent and continuous.

The use of temporary kilns is confined to common brick, but not necessarily to small yards. Such kilns are called scove kilns (Plate L, Fig. 1). For these, the brick are piled up in large rectangular masses from thirty to fifty-four courses high, depending on the clay. Alternate layers head in the same direction, and at right angles to those next above and below.

In building up the kiln, a series of parallel arches is left running through the mass from side to side. After the bricks are set up

[1] Some brickmakers judge the completion of burning by test pyramids called Seger cones. These are artificial mixtures of definite fusion points. Most common brick are burned at about cone 010 whose theoretic melting point is 1050° C., while pressed brick are often fired to cone 7 or 8, about 1280° C.

they are surrounded by a wall of bricks two layers deep, and the whole outside daubed with wet clay to prevent the entrance of cold air during burning. The top of the kiln is then closed by a layer of brick laid close together to keep the heat in.

In some cases, permanent side walls with fire boxes are built.

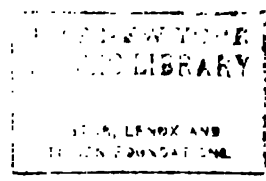
It is very easily seen that the scove kiln will give a variable product. Those bricks around the arches receive the most heat, those in the farthest corners the least, while the normally burned ones are mainly in the center. Sorting is therefore necessary in every case. Many brick burned in this manner have coal dust added to the clay during molding, so that the burning of this during firing will add to the temperature of the kiln. The ash from these coal specks is often seen in the interior of the brick and supposed by many to greatly detract from their strength. This, however, is not probable.

The permanent intermittent kilns, which are used for burning all kinds of brick, have permanent walls and roof, and yield much better results. They are either of up- or down-draft character. In the former the heat from the fire box enters the kiln chamber in the lower part, passes up through the brick and out through flues at the top. In the latter the heat enters the upper part of the kiln chamber first, passes down through the kiln and is drawn out through flues at the bottom. The brick, therefore, which receive the most heat will be those in that portion of the chamber which the fire enters. For this reason the bricks in the bottom of up-draft kilns are often harder burned than those at the top, while in down-draft kilns the reverse is true. The larger the kiln the more difficult it is to get uniform results throughout. This is especially noticeable at times, where the brick are being burned for color. The same kiln, if a large one, might yield eight or ten different shades.

In the continuous system of burning, the kiln is composed of a series of compartments or chambers separated by permanent or temporary walls, these being connected with each other and also with the stack by a system of flues. The waste heat from any given chamber is utilized by being drawn through several others before passing to the stack and serves to heat them up to

PLATE L, Fig. 1. — Setting brick for a scove kiln.
(After Ries, N. J. Geol. Surv., VI, 1900.)

PLATE L, Fig. 2. — Down-draft kilns used for burning sewer pipe.
(Photo from Robinson Clay-Product Co.)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a certain point, beyond which the firing is continued by the introduction of coal slack through openings in the chimney. The use of these kilns is increasing, but they do not give good results where color effects are desired.

Whatever system of burning is employed, care and slowness are essential. The clay must first be carefully heated to drive off the moisture. If carbon or sulphur are present these must also be carefully expelled when the kiln reaches a red heat, and before fire shrinkage begins, in order to prevent the formation of black cores and swollen brick.

No brickmaker ever gets 100 per cent, or probably even 85 per cent perfect brick. Not a few are roughened, discolored and distorted by overfiring or other causes, and these, in the manufacturer's opinion, have usually been regarded as worthless. But it is these rejects that in many cases have appealed to the architect, and as a result of the demand for them, the " culls " have not only assumed a good market value, but in some districts the brickmaker has been called upon to turn out hundreds of them. This may give him even more trouble than producing a kiln of normally burned brick, and he consequently demands a good price for them.

At one brick works, for example, the manufacturer was called upon to fill a large order for some bluish-black brick with a blistered and pimpled surface. This was accomplished only by careful overfiring and shutting off as much air as possible from the kiln during the later stages of burning.

In a large city of the Pacific Coast, dozens of exterior chimneys on private dwellings are constructed of the warped, partly fused, overburned product from a local paving-brick works. If these had not caught the fancy of the architect they would be a loss to the manufacturer.

The smooth-faced, monotone, evenly burned brick is not in favor at the present time, except for special purposes.

Comparison of Brick made by Different Processes. The question is often asked, how brick made by different processes compare with each other. A few points on this may, therefore, be desirable.

Soft-mud brick possess a more homogeneous structure than those made by other processes, as well as being thoroughly durable when well burned. They lack the smooth surface and sharp corners of the dry-pressed ones. Stiff-mud brick when made of the proper clay and molded in a machine adapted to the raw material also show a good structure, but the laminations found in many are an objection. It is easier to make a mis-selection of clay in this process than in the soft mud.

Dry-press bricks present a finished appearance without further treatment, not requiring repressing as in the case of soft-mud and stiff-mud wares. Owing to the granular character of the clay there is a lack of cohesion between the particles, and the resulting brick is softer than one made by the mud processes, unless it is well burned.

Taking the results of a large number of tests no one method gives a brick of higher average strength or density than the others.

Testing of Brick. The tests which can be applied to bricks are: 1, crushing test; 2, transverse test; 3, absorption test and porosity; 4, abrasion test; 5, frost resistance; 6, fire test; 7, permeability.

All of these are rarely carried out. Usually it is only 1 and 3 for structural brick, and 1, 3 and 4 for paving brick.

Crushing Test. The test to determine a brick's crushing strength is made in a specially constructed machine. Half bricks are usually tested, because a whole brick has so large a surface area that it might resist greater pressure than could be applied by the testing apparatus.

Before crushing, the two opposite surfaces of the brick (in this case the top and bottom) must either be ground very smooth and parallel, or else they must be built up to this condition by the application of a layer of plaster of Paris. Paper or cardboard are sometimes used as substitutes for plaster. The reason for this is that in the testing machine the brick is set between two steel surfaces and unless its surface fits perfectly against these the pressure will not be evenly distributed.

In order to show the effect of the method employed in preparing samples for the crushing tests, some experiments were

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made by the Iowa Geological Survey [1] on a parallel series, consisting (1) of accurately ground 2-inch cubes, and (2) of one-third of a brick placed flatwise, with plaster of Paris between the brick surface and the plate of the testing machine.

The results obtained with the plaster of Paris were invariably lower, sometimes as much as 6000 pounds per square inch, but mostly not over 1000 pounds. In a few cases the plaster series gave higher tests.

Brick show a wide range of crushing strength, running from as low as 500 pounds per square inch up to 12,000 or 15,000 pounds, or even more.

We cannot, in the present state of our knowledge, lay down any rule bearing on relation of method of manufacture to crushing strength.

It may be said in general, however, that the crushing strength increases usually with the hardness of burning. The following figures bring out this point:

	Crushing strength, normal burned.	Pounds per square inch, hard-burned.
I	4933	11,058
II	993.3	1,996.6
III	1500	4,852.5

Common brick often show a crushing strength of 2500 to 3000 pounds per square inch and even more.

Hard-burned brick not infrequently run 10,000 and 12,000 pounds and sometimes very much higher.

There is not necessarily any direct relation between the crushing strength and the transverse strength, abrasive resistance, absorption or frost resistance.

Repressing often increases the crushing strength.

The crushing strength increases primarily with the increased hardness of burning, and secondarily with the decrease in pore space.

A burned clay product will not be uniformly strong in all directions, and the method of manufacture may impart to it

[1] Iowa Geol. Surv., Vol. XIV, p. 562.

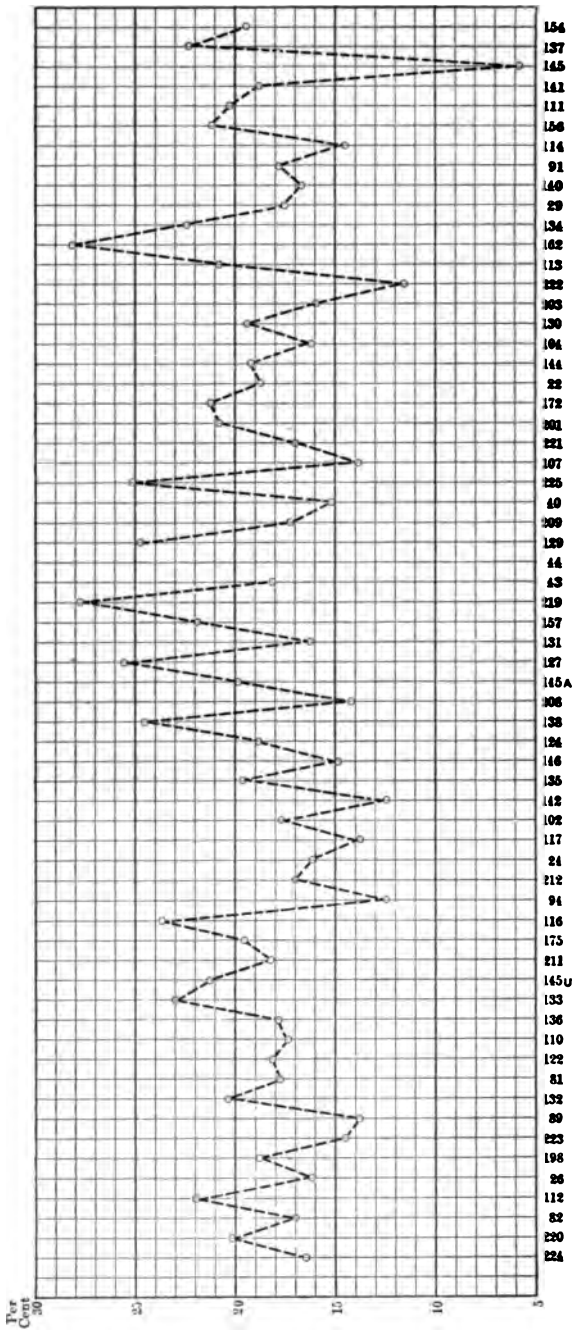

Fig. 10. — Diagram showing absorption tests on Wisconsin soft-mud brick after forty-eight hours immersion.

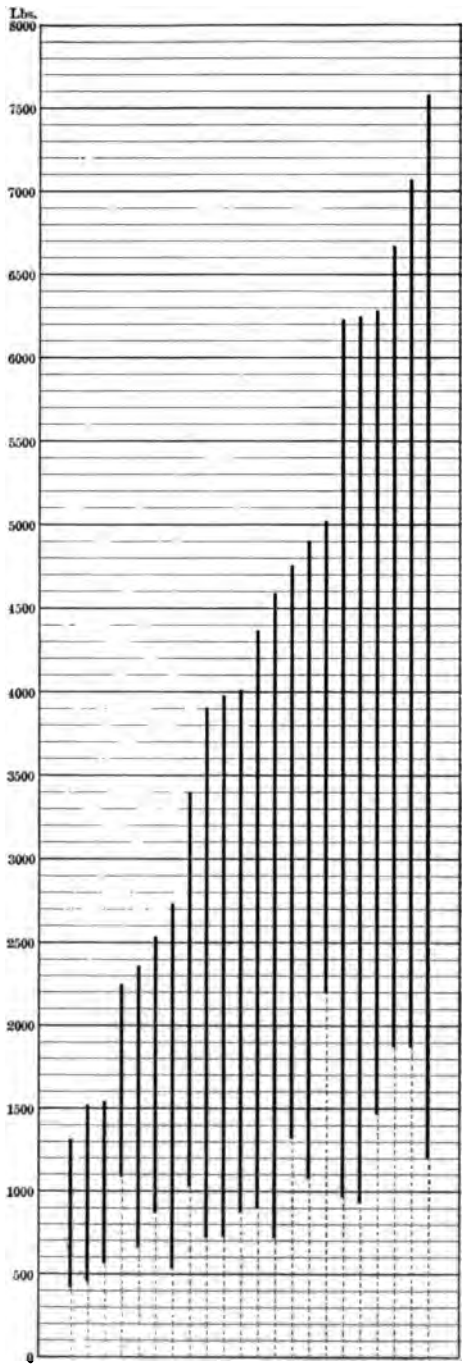

Fig. 11. — Diagram of crushing and transverse tests on Wisconsin stiff-mud brick.
(After Ries, Wis. Geol. Surv., Bull. XV.)

greater strength along one plane than another. Auger laminations may be regarded as influencing abnormal structure.

As a matter of fact, clay products are never taxed beyond their compressive strength.

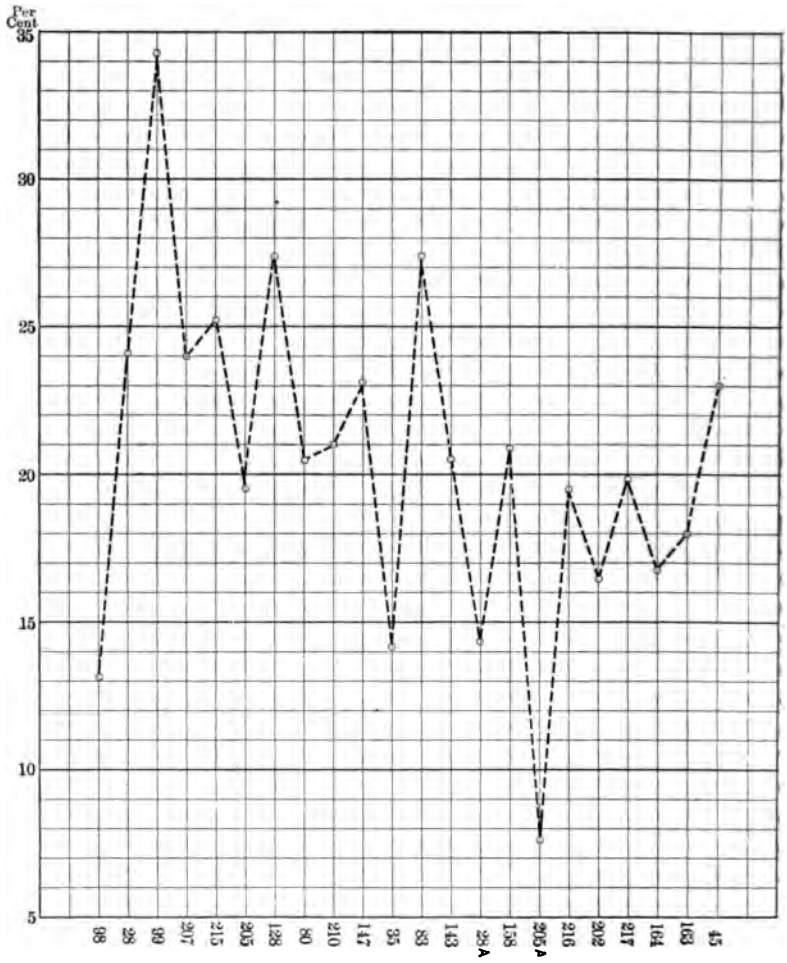

Fig. 12. — Diagram showing absorption tests on Wisconsin stiff-mud brick after forty-eight hours immersion.

In testing the crushing strength of a brick, the latter is usually laid flatwise. Some objection has been raised to this on the ground that there is a large experimental error due to shape.

Theoretically, the best form of test piece is that of a cube, or still better a prism of square cross section, the height of which is $1\frac{1}{2}$ times the breadth, as this gives symmetrical fracture planes.

A custom followed in Germany is to use two half bricks cemented together by a thin joint of Portland cement mortar. This gives a prism and yields satisfactory results.

An advantage claimed for testing a brick on edge is that the failing point can be more sharply detected than when the brick is tested flatwise.

One objection to testing brick on edge is that it does not represent the position of the brick when in use; however, this is unimportant, since the compression strength *per se* has no practical value, except in so far as it differentiates between good and poor materials. But since the flatwise test is liable to serious errors, it is clear that the advantage must lie with the edgewise method which affords more reliable comparative data.

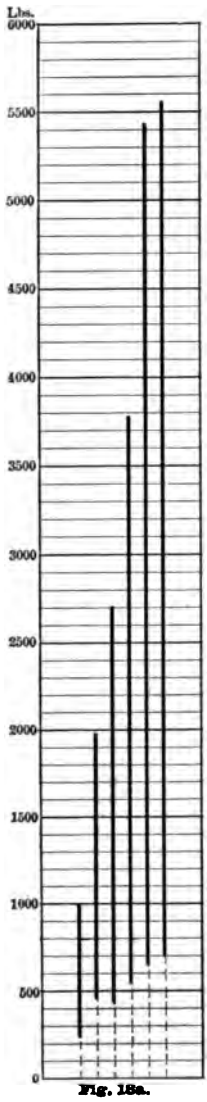

Fig. 13a.

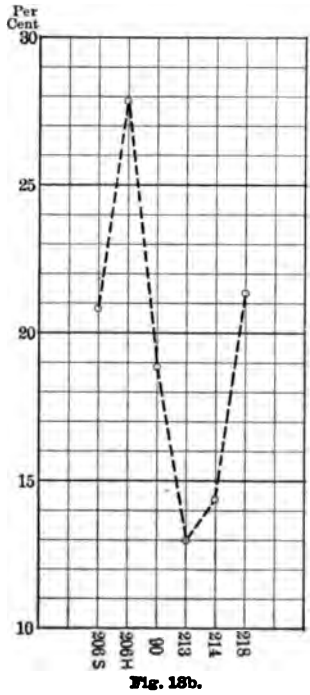

Fig. 13b.

Fig. 13. — (*a*) Diagram of crushing and transverse tests on Wisconsin dry-pressed brick. The upper end of each line represents the crushing strength and the lower end the modulus of rupture. (*b*) Absorption tests of same series. (After Ries, Wis. Geol. Surv., Bull. XV.)

It is not possible to calculate from the strength on edge what it will be when the brick is tested flatwise, or vice versa, except for one and the same brick, since the structure plays such an important rôle.

It is said that a side-cut brick will show a different compressive strength, when tested on edge, from an end-cut one made from the same clay.

The following table taken from the War Department's report on Tests of Metals, etc., for 1895, shows that the compressive strength of a wet brick is usually lower than that of a dry one.

COMPRESSIVE STRENGTH OF WET AND DRY HALVES OF THE SAME BRICK.

Manufacturers.	Description.	Compressive strength per square inch.		
		Dry.	Wet.	Loss.
		Pounds.	Pounds.	Pounds.
Gay Head Clay & Brick Co., Chelsea, Mass.	Buff	5,774	4,900	874
	Buff	5,570	5,346	244
	Buff speckled	6,481	5,063	1418
	Fire brick	2,630	2,321	318
New England Steam Brick Co., Providence, R. I.	Red, No. 1	5,777	4,506	1271
	Red, No. 2	7,888	8,917	−1029
	Red, No. 3	10,624	10,482	142
	Red, No. 4	11,353	8,088	3265
	Light hard, water struck	5,601	4,530	1071
	Hard body	9,655	6,230	3425
	Light buff, No. 55	3,599	3,289	310
	Paving	10,712	9,902	810
The Powhatan Clay Manufacturing Co., Richmond, Va.	Cream white, No. 1	4,929	4,142	787
	Light red, No. 3	16,019	14,822	1197
	Cream white, No. 1	4,447	4,052	395
The Coaldale Brick & Tile Co., Coaldale, Ala.	Vitrified paving, A	15,842	11,273	4569
	Fire, No. 1	2,414	1,885	529
The A. O. Jones Brick & Terra Cotta Co., Zanesville, O.	Vitrified paving block	11,942	7,941	4001
Kansas City Hydraulic Press Brick Co., Kansas City, Mo.	Red, No. 1	18,072	11,911	6161
	Red, No. 2	12,000	12,652	−652
Monticello Brick Works, Monticello, Minn.	Face, No. 2	16,018	15,611	407
A. Humphrey, Minneapolis, Minn.	Light chocolate, No. 71	7,724	7,037	687
Pacific Clay Manufacturing Co., Los Angeles, Cal.		2,073	2,778	105
Mean		8,039	6,835	1204
Relative strength, per cent		100	85	15

Transverse Test. This is a more important test even than the crushing strength, for, while the brick is rarely loaded up to its crushing limit, it is sometimes exposed to its limit of elasticity and cracked. This can, perhaps, be better understood if the manner of making the test is first explained.

In the cross-breaking test a whole brick is placed on two rounded knife-edge bearings. Pressure is applied from above, at a point midway between the two supports, until the brick breaks in two, and the number of pounds at which this occurs is noted.

It is evident that in two bricks of exactly the same degree of strength, the amount of pressure necessary to break them will depend upon (1) the distance between the supports and (2) the cross section of the brick.

The farther apart the supports the less pressure necessary to break the brick, and the greater the cross section the greater the pressure necessary.

Since this is so, it is necessary that for purposes of comparison all results of the breaking strength be reduced to some uniform expression which shall take account of the differences in length, width and thickness of the brick.

The most accurate expression is that termed the ***modulus of rupture***, which is calculated from the following formula:

$$R = \frac{3\,wl}{2\,bh^2}, \text{ in which}$$

R = modulus of rupture,
w = pressure necessary to break the brick,
l = distance between supports;
b = breadth of brick,
h = thickness of the brick.

Cavities, pebbles and clay lumps seem to affect the transverse strength more than the crushing strength.

There is often great lack of uniformity of different individual specimens tested. This may be due to irregularity in burning, a fact often overlooked by engineers and architects.

The transverse test indicates the character of the brick's structure. It is claimed that the finer grained, more uniform and dense the structure of the brick, the higher its transverse strength; the better burned, the higher the transverse strength.

As mentioned above, there is no definite relationship between modulus of rupture and crushing strength, and this fact is also brought out in the tables.

Absorption Test. An absorption test is made for the purpose of determining how much water a brick will absorb when soaked in water, it being supposed by many engineers, architects and others that the percer tage of absorption stands in direct relation to the frost resistance of the brick. This is not so.

In the first place there are several ways of making the test, which yield somewhat different results. It may be made, (1) by complete immersion, usually for forty-eight hours, but sometimes even longer. (2) By partial immersion, and this for but a few hours, or longer, there being no standard rule. (3) By complete immersion in a vacuum.

In discussing these it should be remembered that in making such a test we are endeavoring to imitate at least approximately the conditions to which the brick will be actually exposed when in use, and that we are not doing so will be apparent to anyone on a moment's reflection. When placed in a wall, a brick, unless set in damp ground or water, absorbs moisture only from one side, the side exposed to the weather and on which the rain spatters. So it probably soaks up much less than it does when tested in the laboratory.

In whatever way the absorption test is made, the brick is first thoroughly dried and weighed. After soaking, the excess of moisture is wiped off the surface and it is weighed again, the percentage of absorption being calculated in terms of the original dry weight.

The results obtained by the several methods of testing are well brought out in a series of tests made on nearly ninety different lots of Wisconsin brick.[1]

Three pairs of half brick of each kind were used. One pair was completely immersed for 48 hours. A second pair was half immersed and its absorption measured at the end of 4 hours and again after an additional 44 hours' soaking. A third pair was completely immersed in water under a vacuum, so that the brick probably became completely saturated or nearly so.

In the first of these tests, viz., complete immersion of 48 hours' duration, the percentage of absorption ranged from 5.8 per cent to 34.30 per cent.

[1] Wis. Geol. and Nat. Hist. Surv., Bull. XVI, 1905.

In the partial immersion test it was found that in nearly every case the brick at the end of four hours had absorbed over 90 per cent of the total quantity they were capable of absorbing after 48 hours' partial immersion. The method of manufacture and degree of density did not appear to affect the result in any way whatever.

When immersed in water under a vacuum, the percentage of absorption ranged from 15.70 per cent to 39.90 per cent, and, as might be expected, the amount of water absorbed was greatly increased, so that the per cent gain for any one set ranged from 2.3 per cent to 69.6 per cent.

No direct relation existed between the absorption and crushing strength.

In making an absorption test it is better to make it on a half brick.

The absorption will be less the harder the brick is burned, but this is less noticeable in very sandy clays. Repressed brick may show a lower absorption than unrepressed ones made from the same mixture and burned under the same conditions. Color is not necessarily a guide to the absorption power, except possibly when comparing bricks from the same kiln, in which case the darker ones, being commonly harder burned, may show less absorption.

Absorption and porosity are not the same. Porosity refers to the amount of pore space in the brick. Absorption is expressed in percentage terms of the dry weight of the brick; porosity is expressed in terms of its volume.

The porosity may be determined by the following simple formula suggested by Purdy:

$$\text{Percentage porosity} = 100\left(\frac{(W - D)}{(W - S)}\right),$$

in which W = saturated weight,
D = dry weight,
S = weight of brick suspended in water.

The saturation may be obtained by soaking the brick in water in a vacuum or by soaking for an hour in boiling water, the latter method being probably just as accurate.

A series of tests made by J. C. Jones,[1] indicated that the percentage of absorption does not bear any constant ratio to the per cent of porosity.

The porosity of clay products is, however, an important factor, probably, in their durability, and certainly in their cleanliness and non-conductivity of heat. If a brick is very porous the dirt will lodge in its pores and spoil its appearance, and this applies more strongly to some other types of clay wares, as terra cotta.

While no direct ratio exists between absorption and porosity, still we can say that a brick of high porosity will usually show high absorption and vice versa.

A few figures from Mr. Jones' tests will illustrate:

	Per cent absorption, 2 weeks' soaking.	Per cent porosity.	Ratio per cent absorption to per cent porosity.
1	.505	1.72	1:3.42
2	.576	2.04	1:3.54
2a	.993	4.25	1:4.28
3	1.08	2.97	1:2.75
4	1.40	4.56	1:3.26
5	1.83	6.26	1:3.42
6	2.94	7.58	1:2.57
7	4.28	10.90	1:2.54
8	6.49	17.0	1:2.61
9	9.66	21.60	1:2.23
10	11.00	23.6	1:2.14
11	11.80	25.8	1:2.18
12	15.10	29.10	1:1.92

Some rather extensive tests on absorption and porosity of building brick by different methods have been made by Douty and Beebe.[2] The results of their tests are given in the following table.

[1] Trans. Amer. Ceramic Society, IX.

[2] "Some Further Experiments upon the Absorption, Porosity and Specific Gravity of Building Brick," Proceedings American Society for Testing Materials, Vol. XI, p. 767; see also "The Influence of the Absorptive Capacity of Bricks upon the Adhesion of Mortar," Proceedings American Society for Testing Materials, Vol. VIII, p. 518, 1908; also, Howard, Engineering News, Vol. 6, No. 10, p. 273, March, 1909.

COMPARISON OF RESULTS FROM FIVE METHODS OF DETERMINING ABSORPTION WITH WHOLE AND HALF SPECIMENS, PREVIOUSLY DRIED TO CONSTANT WEIGHT AT 100° C.

Brick No.	Partial immersion 90 days.				Total immersion 90 days.				Immersion 7 days and boiling 1 hour.			
	Whole.		Half.		Whole.		Half.		Whole.		Half.	
	Wt.	Vol.	Wt.	Vol.	Wt.	Vol.	Wt.	Vol.	Wt.	Vol.	Wt.	Vol.
3	13.4	25.3	16.7	31.6	13.8	26.1	13.9	26.3	14.6	27.6	15.3	28.9
13	12.1	24.4	12.5	25.3	11.5	23.2	10.5	21.2	11.1	22.4	10.5	21.2
22	10.7	21.7	10.4	21.1	10.8	21.9	11.3	22.9	11.2	22.7	10.2	20.7
20	10.6	21.6	11.0	22.4	10.2	20.8	11.0	22.4	11.5	23.5	11.3	23.1
21	9.2	18.4	10.7	21.4	10.3	20.6	10.3	20.6	11.0	22.0	10.4	20.8
8	8.4	17.6	8.9	18.7	10.1	21.2	9.3	19.5	8.9	18.7	8.9	18.7
18	8.0	16.3	8.0	16.3	7.9	16.1	8.1	16.5	8.4	17.1	8.3	16.9
16	3.8	8.4	4.3	9.5	5.1	11.3	4.9	10.9	3.8	8.4	5.0	11.0
15	4.2	9.7	3.5	8.1	3.6	8.3	3.5	8.1	6.3	2.7	4.7	10.9
Average..	.....	18.2	.....	19.4	.....	18.8	.....	18.7	.....	18.3	.....	19.1

Brick No.	Boiling.				Vacuum.				Total immersion 110 days and boiling 4 hours.			
	Whole.		Half.		Whole.		Half.		Whole.		Half.	
	Wt.	Vol.	Wt.	Vol.	Wt.	Vol.	Wt.	Vol.	Wt.	Vol.	Wt.	Vol.
3	14.0	26.5	13.2	25.0	13.1	24.8	13.4	25.3	14.4	27.2	14.3	27.0
13	12.8	25.9	12.8	25.9	9.7	19.6	11.0	22.2	11.9	24.1	11.1	22.5
2	11.7	23.8	11.2	22.7	9.8	19.9	10.5	21.3	11.6	23.6	11.8	24.0
20	11.1	22.6	11.2	22.8	10.7	21.8	10.6	21.6	10.7	21.8	11.3	23.0
21	11.0	22.0	10.2	20.4	10.5	21.0	10.8	21.6	11.2	22.4	10.9	21.8
8	10.0	21.0	10.7	22.5	9.2	19.3	8.0	16.8	10.8	22.7	9.9	20.8
18	8.5	17.3	8.6	17.5	7.2	14.7	7.2	14.7	8.7	17.7	8.7	17.7
16	6.0	13.3	5.6	12.4	3.0	6.7	3.3	7.3	6.0	13.3	5.7	12.7
15	4.1	9.5	4.2	9.7	4.8	11.1	3.5	8.1	4.9	11.4	4.4	10.2
Average..	.....	20.2	.....	19.9	.....	17.7	.....	17.8	.....	20.5	.....	20.0

The methods of making these determinations are explained by them as follows:

"Absorption by weight was obtained from the increase in weight of the specimens used in the determination of the specific gravity of normal brick, maximum absorption.

"Absorption by volume was obtained from the product of the absorption by weight and the specific gravity of normal brick.

It may be observed that these values approach very nearly the values for percentage of voids. That bricks 2 and 16 show higher absorption by volume than percentage of voids may be ascribed to the fact that specimens from bricks with a normal specific gravity higher than the average were probably selected.

" Table III is a comparison of the results obtained by five methods of determining absorption with both whole and half specimens which were previously dried to a constant weight at 100° C.

" In ' Partial Immersion ' the specimens were immersed to a depth of $\frac{1}{2}$ inch.

" In ' Total Immersion ' the specimens were submerged to a depth of $\frac{1}{2}$ inch.

" In ' Total Immersion and Boiling,' the specimens were submerged for 7 days and then boiled for 1 hour. All partial immersion tests were conducted under as uniform conditions of air humidity and temperature as possible, i.e., 100 per cent humidity and about 68° F.

" In ' Boiling ' the specimens were boiled 4 hours and weighed as soon as cool enough to handle and also 24 hours afterwards. In some cases there was a slight decrease after 24 hours and in others an increase.

" In the ' Vacuum Test,' the specimens were subjected to a reduced pressure of about 68 cm. of mercury for 1 hour and, without breaking the vacuum, water was allowed to flow until the specimens were completely covered and then subjected to a pressure of about 35 lbs. for 1 hour.

" As the table given above is primarily a comparison of methods, the averages of absorption may be assumed to indicate the relative values of these different methods."

Rate of Absorption. — The same authors also endeavored to determine the rate of absorption for partial and total immersion of whole and half bricks by weight over an extended period of time.

" At the expiration of 110 days the bricks were boiled four hours and the percentage of absorption obtained in this way was taken as the maximum or 100 per cent. The percentage rate at various periods was computed from this maximum.

"For both whole and half bricks, it was observed that approximate maximum absorption is attained at an earlier period and the rate of absorption is higher in the case of total immersion than partial immersion, except in a few cases which can be accounted for by a variation in the specimens themselves.

"Tests were made on several of the bricks to determine the effects of repeated absorption and drying. After repeating absorption and drying ten times no appreciable change in the percentage of absorption or loss in weight could be observed."

Permeability. — Tests on the permeability of brick have been made by Douty and Beebe[1] for the purpose of determining whether any relation exists between the size or percentage of voids and the absorptive capacity. The tests were made on half brick mounted on Amsler-Laffon permeability apparatus and were subjected to a pressure of about 285 pounds per square inch. The results of these tests are given in the following table.

RESULTS OF PERMEABILITY TESTS.

Brick No.	Specific gravity of normal brick, dried.	Specific gravity of ground material.	Voids, per cent.	Permeability, cu. cm. per sq. cm. per min.	Absorption by volume, per cent.
3	1.89	2.66	28.9	1.600	26.5
13	2.02	2.64	23.5	0.500	21.5
2	2.03	2.60	21.9	1.957	22.7
20	2.04	2.65	22.9	2.000	22.8
21	2.00	2.60	23.1	3.230	21.2
8	2.10	2.64	20.5	0.844	18.4
18	2.04	2.51	17.7	0.570	17.2
16	2.22	2.64	10.9	0.282	12.4
15	2.32	2.64	12.1	0.594	6.8

As stated in their paper the data are considered incomplete because they were confined to a limited number of specimens and a comparison of the last three columns of the preceding table would seem to indicate that the largest values of permeability are obtained for those brick in which the absorption by volume nearly approaches the percentage of voids.

[1] "Some Further Experiments upon the Absorption, Porosity and Specific Gravity of a Building Brick," Proceedings American Society for Testing Materials, Vol. XI, p. 767.

Relation between Crushing Strength, Transverse Strength and Absorption. There seems to exist a strong misconception on this point.

The compressive strength cannot be correlated with the absorption, except when such comparison is restricted to samples of the same clay, molded and burned under uniform conditions.

There is, as already mentioned, no definite relation between the transverse and crushing strength, and this fact is also brought out in the tables.

A brick of low transverse strength may be of good crushing strength and vice versa.

The lack of definite relation between the crushing strength, transverse strength and absorption is shown by the following figures taken from a series of tests made on a number of Wisconsin brick.

Kind of brick.	Average crushing strength.	Average modulus of rupture.	Per cent absorption.
Soft mud	1192	526	20.35
Soft mud	4572	569	14.4
Soft mud	3036	1063	18.7
Soft mud	5790	1062	22.25
Stiff mud	1540	588	34.3
Stiff mud	2708	550	27.6
Stiff mud	2234	1097	24.15
Stiff mud	4090	1090	20.85
Stiff mud	1540	588	34.3
Stiff mud	5110	2190	.....
Soft mud	1192	526	24.65
Soft mud	4572	569	14.4

Fire Tests. Freitag[1] states that "many fires have fully demonstrated the fire-resisting qualities of good brickwork. Its ability to withstand fire and water tests depends on: (*a*) the method of manufacture, (*b*) the chemical properties of the materials employed, (*c*) the method of use.

"Both the Baltimore and San Francisco fires demonstrated that good quality brickwork, used for walls or column casings, suffered less than any other material.

[1] "Fire Prevention and Fire Protection," p. 219.

"Ordinary well-burned brick of good quality is the most satisfactory fire-resisting material now used in building construction. When the walls were laid with hard brick, with plenty of headers and in portland cement mortar, and were properly tied to the floor and roof members, there was little if any damage."

A fire test of brick is of great importance.

When such a test is made, it is customary to heat a sample of the brick to redness in a furnace and then plunge it into cold water. This may be satisfactory if no other means is at hand.

A far better, though expensive, plan is that formerly followed in the fire-testing station of Columbia University, under the direction of Professor I. A. Woolson.

A house was constructed with exterior dimensions of 14 feet 6 inches by 9 feet 6 inches, consisting of reinforced concrete walls and roof, while the side walls were removable. The floor of the building is a grate upon which the fire is built and suitable draft openings and chimneys are provided. The sides were built as 8-inch walls of the brick to be tested.

The brick were laid in bands about 14 inches wide, in order that each variety of brick might be subjected to the same heat, and as far as possible only half a band was laid on the same level in the wall; the other half was placed in some other position. The purpose of the test is to determine the effect of a continuous fire against the walls for two hours, bringing the heat up slowly to 1700° F. during the first half hour and maintaining this as nearly as possible during the remainder of the test. Then a one and one-eighth-inch stream of cold water was thrown against the wall for three minutes at hydrant pressure, which varied from 25 to 30 pounds.

In one test several large cracks developed in the walls and the brick themselves were full of cracks. Indeed, it was very difficult to get a whole brick. In general, the brick were affected by the fire about half way through. Samples of the brick tested for their crushing strength after the fire test showed in nearly every case a marked decrease.

A testing furnace[1] in use at the Underwriters' Laboratory of Chicago consists of a gas furnace with "a movable steel frame fire-brick wall or door 14 inches thick that shuts off the furnace from a radiation chamber." . . . "This movable wall has an arched opening 6 feet wide and 9 feet high. The material to be tested is built up in this opening as a panel."

After the panel is filled and shoved into place, the fire chamber is heated by gas. An effort was made to obtain the maximum temperature, 1700° F., within one-half hour after starting the test, and to maintain this temperature as nearly constant as possible for two hours. At the end of this time the panel containing test brick was pulled out and a stream of water from a $\frac{7}{8}$-inch nozzle at 50 pounds pressure directed against the hot surface for a period of five minutes.

These conditions were unusually severe, and the temperatures were those not usually reached in an actual fire.

Much of the damage done was due to internal stresses, because gas flame of the furnace heated one face more rapidly than the other face.

Many of the materials were poor non-conductors of heat, the natural building stones and tiles proving specially bad in this respect. This naturally set up stresses which the webs of ordinary hollow blocks were insufficient to resist.

Brick panels withstood tests better than other materials and comprised unused new Chicago brick and used St. Louis brick. Fifty per cent of the new brick were split, while 60 to 70 per cent of the old brick were not damaged. Lime knots apparently caused damage. The bricks at back of panels were unaffected.

Hydraulic pressed brick stood the test very well and 70 per cent were found sound after quenching.

The tile tested behaved badly. One was a hollow-glazed building tile, 8 by 8 by 16 inches, with $\frac{1}{2}$-inch web and four core holes running throughout its length. The other, a partition tile, 5 by 12 by 12 inches, with a $\frac{5}{8}$-inch web, and three core holes.

[1] U. S. Geol. Survey, Bull. 370.

Unfortunately, no detailed and conclusive series of tests have been made to determine the relative fire resistance of brick made by different methods.

Vitrified bricks will usually spall badly when subjected to fire and water treatment. Stiff-mud brick, if at all laminated, show a tendency to split off along the planes of lamination. And yet, brick will on the whole stand fire better than most building stones.

Coefficient of Expansion. The following tests of coefficients of expansion of burned clay wares is of interest in this connection. These tests were made at the Watertown Arsenal,[1] the brick being heated in a hot-water bath.

COEFFICIENTS OF EXPANSION OF BRICKS, AS DETERMINED IN WATER BATHS.

Character of product.	Original gauged length in air.	Hot.	Cold.	Difference.	Difference in length.	Coefficient of expansion.
Red brick, No. 1.....	6.0852	184	34	150	.0032	.00000351
Red brick, No. 2.....	6.0109	184	34	150	.0023	.00000255
Red brick, No. 3.....	5.9396	184	34	150	.0023	.00000258
Red brick, No. 4.....	6.0204	184	34	150	.0029	.00000321
Fire brick, No. 1.....	5.9968	184	34	150	.0026	.00000289
Fire brick, No. 2.....	5.9988	184	34	150	.0022	.00000244
Hollow fireproof building brick.....	10.0036	185	34	151	.0044	.00000291

Frost Test. There is no universally accepted standard method of making this test.

Some engineers take either a whole or half brick, soak it thoroughly in water from two to even five days, and then put it in a refrigerating chamber where it is exposed to a freezing temperature for perhaps 23 hours, followed by one hour thawing at a temperature of about 120° F. This process is repeated preferably about twenty times and the loss in weight or evidence of disintegration noted.

The work of the Iowa Geological Survey on bricks from that state[2] has shown that rough cubes when subjected to the freezing

[1] Tests of Metals, etc., 1890.

[2] Iowa Geological Survey, XIV.

test gave greater losses than smoother and larger ones respectively. Their conclusions were based on 20 hours' freezing and 4 hours' thawing, repeated thirty times.

It has been noticed[1] that the method of placing bricks in a freezing box may also cause difference in the results.

Thus, if the brick are placed close together, the evaporation that takes place from the surface of a warm brick when placed in the refrigerating chamber is retarded. More water remains in the pores, and the brick will be more damaged. If the same brick are separated when placed in the freezing box, a lower percentage of loss or disintegration occurs. This fact was discovered by the different reports made by two laboratories, in testing brick of the same make. The one in which the brick were frozen in a closely set position reported a far greater loss.

There is some doubt as to what are the causes governing the frost resistance of brick, but the common idea is that the harder burned a brick the greater its frost resistance. This theory is based on the fact that with increased hardness of burning, there is an increase in strength and decrease in pore space. It is claimed by some, however, that freezing tests on brick do not bear this out; moreover, the crushing strength of some of the hardest brick is most affected by freezing.

Of course, the degree to which a given brick is affected will depend to a certain extent upon its degree of saturation.

If the pores are not completely filled with water there may be room for the latter to expand in freezing without exerting any internal pressure, while if the pores are filled, then, unless the water can force its way out in freezing, considerable internal pressure may develop.

Jones[2] suggests that the power of a brick to withstand frost action depends on the amount of pore space, the rate at which water can flow through the pores, and the crushing strength.

A very porous brick may drain more easily, provided the pores are large and straight, so that some of the water may drain off before freezing. If the pores are tortuous, the water may not

[1] Tonindustrie Zeitung, XXXII, p. 1846, 1908.

[2] Trans. Amer. Ceramic Society, IX, p. 528, 1907.

only drain off more slowly, but, if it freezes, remain within the brick.

The crushing strength may indicate the relative resistance which a brick will offer to the expansive force of freezing water.

Hard-burned brick have greater strength and greater rigidity than soft-burned ones, and while they have a smaller pore space, and have less water when filled, still they drain more slowly, and, though having greater strength to resist expansion, will rupture with less expansion. A given amount of expansion on freezing might, therefore rupture a rigid brick, when it would not harm a more elastic or a tougher one.

If brick are to be used in the foundation where they are liable to be exposed to moisture it is best to use those of high crushing strength and low porosity.

Proposed Standard Specifications for Building Brick. The following have been proposed by the American Society for Testing Materials.[1]

Selection of Samples. For the purpose of tests, brick shall be selected by some disinterested and experienced person to represent the commercial product. All brick shall be carefully examined, and their condition noted before being subjected to any test.

Transverse Test. At least five brick shall be tested, laid flatwise with a span of 7 inches, and with the load applied at midspan. The knife edges shall be slightly curved in the direction of their length. Steel bearing plates, about $\frac{1}{4}$ inch thick and $1\frac{1}{2}$ inches wide, may be placed between the knife edges and the brick. The use of a wooden base-block, slightly rounded transversely across its top, upon which to rest the lower knife edges, is recommended. The modulus of rupture shall be obtained by the following formula:

$$R = \frac{3\,We}{2\,bd^2},$$

in which e is the distance between supports in inches, b is the breadth and d the depth of the brick in inches, and W is the load in pounds at which the brick failed.

[1] Vol. IX, p. 131.

The half bricks resulting from the transverse test shall be used for the compression and absorption tests. One half shall be crushed in its dry condition; the other half shall be used for the absorption test and crushed while in its wet condition. No specimen shall be used if any part of the line of fracture is more than 1 inch from the center line.

Compression Test. Compression tests shall be made on half brick resulting from the transverse test. The brick shall be bedded flatwise on blotting paper, heavy fibrous building paper or heavy felt, to secure a uniform bearing in the testing machine. In case the brick have uneven bearing surfaces, they shall be bedded in a thin coat of plaster of Paris. For the dry test, before applying the plaster of Paris, the bearing surfaces of the brick shall receive a coat of shellac. The machine used for compression tests shall be equipped with spherical bearing blocks. The breaking load shall be divided by the area in compression, and the results reported in pounds per square inch.

Absorption Test. At least five half brick shall be first thoroughly dried to constant weight, at a temperature of from 200° to 250° F., weighed, and then placed on their face in water to a depth of 1 inch in a covered container. The brick shall be weighed at the following intervals: one-half hour, six hours, and forty-eight hours. Superfluous moisture shall be removed before each weighing. The absorption shall be expressed in terms of the dry weight, and the balance used must be accurate to 5 grams.

Freezing and Thawing Tests. In case the freezing and thawing test is desired, at least five brick shall be thoroughly saturated by immersion in cold water, which shall be raised to 200° F. in thirty minutes, and then allowed to cool. The specimen shall be immersed in ice water for not less than one hour, weighed, then transferred to the refrigerator and supported in such a manner that all faces will be exposed. The specimen shall be subjected to a temperature of less than 15° F. for at least five hours, then removed and placed in water at a temperature of not less than 150° F., nor more than 200° F., for one hour. This operation shall be repeated twenty times, after which the brick, still saturated, shall be weighed again. The character of the

brick shall be noted before and during the test, and all visible changes recorded. Immediately on completion of this test, the samples are to be thoroughly dried and subjected to the transverse and compression tests.

Requirements. The following requirements shall be met. The modulus of rupture shall be as follows:

	Average, lbs.	Minimum.
For samples thoroughly dry	400	325
For samples thoroughly saturated	275	225
For samples subjected to freezing and thawing process	275	225

The ultimate compression strength shall be as follows:

	Average, lbs. per sq. in.	Minimum, lbs. per sq. in.
For samples thoroughly dry	3000	2500
For samples thoroughly saturated	2500	2000
For samples subjected to freezing and thawing process	2500	2000

The absorption shall not average higher than 15 per cent, and in no case shall it exceed 20 per cent.

The freezing and thawing tests shall not cause cracking or serious spalling in any of the brick tested, nor cause serious disintegration of the material.

Specific Gravity. The specific gravity of a brick is sometimes considered in connection with other tests upon its qualities, but comparatively few data have been published upon this matter. Recently Douty and Beebe [1] made some determinations on the specific gravity of ground material, as well as of the normal brick. For this purpose four samples covering a range of variation were selected and the specific gravity of the ground material passing different sizes of sieves was obtained. Brick samples were first crushed to pass a number 20 sieve,

[1] "Some Further Experiments upon the Absorption, Porosity and Specific Gravity of a Building Brick," Proceedings American Society for Testing Materials, Vol. XI, p. 767.

thoroughly mixed and then divided into portions to be subsequently crushed to pass sieves of 40, 60, 80, 100 and 200 mesh. These determinations were made with a Le Chatelier flask after all moisture had been driven off and the results of the tests are given in the table below.

COMPARISON OF THE SPECIFIC GRAVITIES OF GROUND MATERIAL TO PASS DIFFERENT SIZES OF SIEVES.

Le Chatelier Flask.

Brick No.	Sieve number.					
	20	40	60	80	100	200
2	2.568	2.590	2.600	2.604	2.613	2.636
18	2.457	2.490	2.506	2.522	2.533	2.547
10	2.462	2.510	2.538	2.545	2.552	2.580
13	2.582	2.626	2.644	2.648	2.659	2.689
Pyknometer.						
18	2.433	2.487	2.517	2.527	2.534	2.550

A series of check determinations on brick was made with the pyknometer and reference to the table shows that there is a marked increase in the value of the specific gravity up to number 60 sieve. In subsequent comparisons, therefore, the specific gravity of the ground material passing through a number 60 sieve was used by them as a basis.

COMPARISON OF THE SPECIFIC GRAVITIES OF NINE BRICKS WITH ABSORPTION BY THE BOILING METHOD.

Brick No.	Specific gravity of ground material.	Specific gravity of normal brick, maximum absorption.	Specific gravity of normal brick, dried.	Voids,[1] per cent.	Absorption by weight, per cent.	Absorption by volume, per cent.
3	2.66	2.64	1.89	28.9	14.02	26.5
13	2.64	2.64	2.02	23.5	10.62	21.45
2	2.60	2.61	2.03	21.9	11.20	22.7
20	2.05	2.62	2.04	22.9	11.20	22.8
21	2.60	2.58	2.00	23.1	10.62	21.2
8	2.64	2.59	2.10	20.5	8.78	18.4
18	2.51	2.48	2.04	17.7	8.45	17.2
16	2.64	2.58	2.22	10.9	5.60	12.4
15	2.64	2.53	2.32	12.1	2.95	6.8

[1] Percentage of voids $= 100 - \frac{\text{Specific gravity of normal brick, dried}}{\text{Specific gravity of ground material}} \times 100.$

In the preceding table there are given the specific gravities of nine bricks together with their absorption by the boiling method.

To quote further from them:

"The specific gravity of normal brick, maximum absorption, was obtained by boiling quarter portions of the samples for 4 hours in hydrant water and determining the specific gravity by the method of suspension in distilled water, correction being made for the higher specific gravity of water absorbed. As may be noticed, the values in this column very nearly approach the values for the specific gravity of ground material and would probably equal them if maximum absorption had been obtained.

"The specific gravity of normal brick dried was obtained by drying quarter portions of the brick to constant weight, coating with shellac varnish and baking in an oven at approximately 215° F. until hard, repeating the process of coating and baking until the absorption was so slight as to not materially affect the values obtained by the suspension method. The specific gravity of the shellac was found to be 1.067 and a correction made to allow for the coating.

"The ratio of the specific gravity of the normal brick dried to the specific gravity of the ground material, multiplied by 100, expresses the percentage of solid matter present in the normal brick; this subtracted from 100 per cent gives the percentage of voids.

"Absorption by weight was obtained from the increase in weight of the specimens used in the determination of the specific gravity of normal brick, maximum absorption.

"Absorption by volume was obtained from the product of the absorption by weight and the specific gravity of normal brick. It may be observed that these values approach very nearly the values for percentage of voids. That bricks 2 and 16 show higher absorption by volume than percentage of voids may be ascribed to the fact that specimens from brick with a normal specific gravity higher than the average were probably selected."

Efflorescence or Scum on Brick.[1] Many brick after being set in the wall develop an unsightly white scum, while on others it may show before it leaves the factory. This stain can often be prevented if brickmakers and builders take the proper precautions.

It is without doubt more or less unsightly and may harm the brick.

In view of all this it is well for the architect to know something of the cause of this efflorescence and methods of preventing it.

The scum is due to the presence of soluble compounds such as sulphates of lime, magnesia, potash, or soda, in the burned or unburned clay, which are brought to the surface when the water in the ware evaporates.

The causes of efflorescence are classified by Gunther[2] as follows:

I. Efflorescence from causes due to
   1. Raw clay.
   2. Water used in tempering.
   3. Firing, and caused by
      a. Ingredients of the coal ash.
      b. Sulphur in the coal.
      c. Pyrite in the clay.

II. Efflorescence from mortar due to
   1. Infiltration of soluble salts into the brick.
   2. Chemical reactions between the alkalies of the mortar and lime sulphate in the clay.

Efflorescence due to the raw clay or water used for mixing forms on the surface of the ware during the drying process, so that bricks coming from a dryer sometimes show this white scum very clearly. This may be termed dryer white. When due to the clay, the soluble salts may be primary constituents of the clay and removable by leaching, or they may develop in the clay if the latter is exposed to the weather for any length of time.

[1] *References on Scumming.* Seger's collected writings. Gunther, Baumaterialienkunde, XXIV and XXV, p. 385; also Tonindustrie Zeitung, XXX, p. 583; Gerlach, Brickbuilder, 1899; J. C. Jones, Trans. Amer. Ceramic Society, VIII p. 369; E. Lovejoy, Trans. Amer. Ceramic Society, VIII, p. 255, 1906.

[2] Baumaterialienkunde, 1896–97, p. 385.

The preventive methods consist of (1) using unweathered clay, (2) removing soluble salts present by leaching, if possible, (3) by adding chemicals such as barium chloride or carbonate which will convert them into an insoluble form.

Kiln white is chiefly lime sulphate, formed by the action of the sulphurous gases of the fuel on lime in the clay, or by the oxidation of iron sulphide to iron sulphate, which is soluble.

It may become burned into the brick and be difficult of removal.

Wall white is a scum which forms on a brick wall and can be rubbed off.

It appears to consist mostly of sulphates of lime and magnesia, but soda and potash sulphates may also be present.

Wall white may be caused by soluble salts contained within the brick, or it may come from the mortar or even the mortar color. If from the mortar, it may be due to carbonates of magnesia, soda or potash washed out of the cement, reacting with lime suphate in the brick, forming lime carbonate, which is quite insoluble and remains in the brick, while the magnesium, sodium or potash sulphates formed are carried to the surface.

The remedies for wall white are to make the walls as impervious to water as possible, or use well-burned brick and coat the foundations with waterproof paint.

Painting a wall after the scum has appeared is often productive only of temporary improvement, as the scum and paint may peel off.

Testing Brick for Scumming Power. There is no standard method of testing this, but the following is suggested by Mäckler.[1] Experiments made by him showed that gypsum was not the sole cause of scumming. Brick with 1 per cent of gypsum might not scum, while others with but 0.03 per cent of sulphates of potash, soda or magnesia might do so.

The test for determining the scumming power consisted of placing the brick on two glass rods over a shallow dish.

A bottle of distilled water was fastened in an inverted position to the upper surface of the brick, which thus absorbed the water.

[1] Tonindustrie Zeitung, 1905.

The latter passed through the brick, dissolved the soluble salts and brought them to the surface.

Experiments showed that the scumming was not always proportional to the amount of soluble salts present, so tests were made to determine the effect of different salts when the brick were burned at different temperatures.

Small amounts of lime and potash sulphates showed no bad effects, but as little as 0.01 per cent of sodium or magnesium sulphate produced a scum.

Brick which were fired in an oxidizing atmosphere showed slightly more efflorescence than those burned in a reducing fire.

The densest brick showed the most efflorescence, but the size of the pores seemed to be a factor in preventing scumming.

Scumming of a brick or other piece of clay ware might be tested by placing the object partially immersed in a dish of water, protected from dust, and allowing it to remain there. The water is drawn in through the sides of the piece and evaporates from the top, carrying the soluble salts with it.

Requisite Qualities of Brick. There may be a wide divergence of opinion as to what should constitute a good brick, but the author would venture to suggest the following.

Common Brick. Color preferably red. Sufficiently hard burned to give a good ring when struck together. Not necessarily steel hard. Freedom from lime pebbles. Absorption preferably not over 15 per cent, but a good brick may show more. Crushing strength not less than 2000 pounds per square inch. Modulus of rupture preferably not under 300 pounds. If stiff-mud, freedom from laminations. Good frost-resisting qualities.

Pressed Brick. Steel hard if possible. Freedom from lime pebbles and soluble salts. Crushing and transverse strength at least as high as in common brick, but is usually much better. Absorption preferably low. For certain purposes smoothness of surface, sharpness of corners and straightness of edges are demanded. Indeed, exactness of form and outline represent the attainment of a high degree of mechanical perfection.

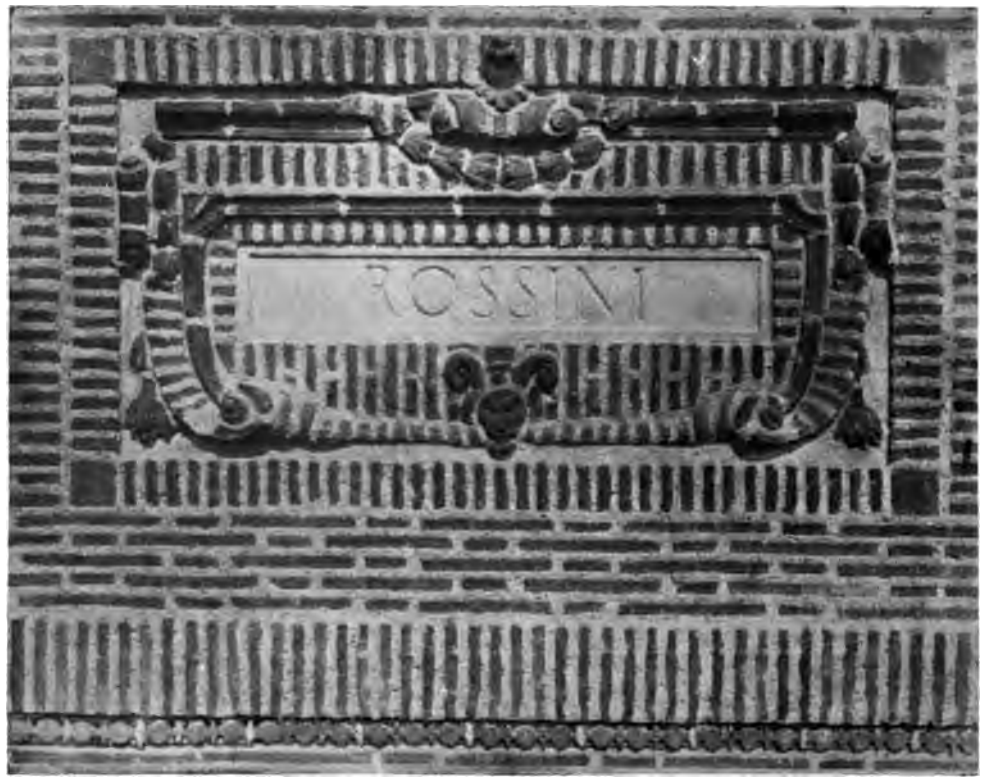

Plate LI. — Brickotta, a style of ornamental brickwork.
(Photo loaned and copyrighted by J. Parker Fiske.)

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In the early years of the pressed-brick industry, the product exhibited a great monotony of color and the smooth red brick front was the rule.

In recent years, however, there has been a marked change, and facing bricks are now made in buff, white, gray, speckled, tan, old gold, white, black, green, etc.

The production of this variety in colors is due in part to proper selection and understanding of the raw material, but also to technical skill in handling the burning.

Of equal interest is the recent tendency to depart from the smooth surface front brick, set with narrow mortar joints, and to select instead a rougher faced product, set in thick mortar seams. Absolute uniformity of shade in the same wall face is also objected to by many architects.

It is no doubt true that there is here a gain in both structural and decorative effect.

A recent development in artistic brickwork is known as " Brickotta " (Plate LI). It is a form of terra cotta, which is hand molded and hand finished, being divided into units corresponding approximately to brick sizes. It is made of the same color and texture as the surrounding brickwork.

Enameled Brick. The bricks may be made on stiff-mud or soft-mud machines, and repressed, or in a dry press.

They are then usually dipped by hand in a slip, which shows the desired color after burning, and then a glaze is applied over the slip.

At one works an automatic veneering process is used, which consists in having a special device attached to the die of a stiff-mud machine, so that the slip is spread on the column of clay in a thin layer as it issues from the machine.

Enameled bricks are usually burned in one firing, following the application of the slip and glaze, but in some cases the brick may be burned before slipping, and then receive a second firing after the application of slip and glaze. The two-fire method increases the cost of manufacture.

Defects in the enamel, such as pinholes, cracks, etc., may be caused by improper preparation of the slip, bad dipping, etc.;

crazing, cracking and scaling of the enamel may also be the result of improper composition of body and slip, etc.

The enameled brick formerly manufactured were chiefly of white color, but now a variety of colors are made, and the product, although first obtained exclusively from abroad, is now made at a number of localities in the United States.

Two sizes are recognized, viz., the English (9 by $4\frac{1}{2}$ by 3 inches) and the American ($8\frac{3}{8}$ by $4\frac{1}{2}$ by $2\frac{3}{8}$ inches).

A good brick should have an enamel which is smooth, free from pinholes or bubbles and crazing. The last does not at times appear until the brick has been in use for several months.

Enameled brick were formerly made only with a full-glazed surface, but now matt glazes and semi-lustrous glazes are also made.

Where enameled brick are used in damp situations, they unfortunately show a tendency to flake off after the course of a few years.

The agencies likely to work injury to an enameled brick are: Frost, crystallization of soluble compounds in the brick, corrosive liquids or vapors, pressure, change of temperature, scouring action and percussion.

There are no standard methods for testing enameled bricks, but the following ones have been suggested:

1. Immerse the brick, enameled face down, to a depth of one inch in a hot, saturated solution of brine. After soaking, remove and cool, repeating the treatment a number of times. A poor brick may craze after 1 or 2 soakings, while a good one will stand this treatment at least 5 or 6 times.

2. Since dirty liquids cause discoloration by penetrating the pores of the brick behind the glaze, soak the brick in red ink. The stain will spread through the clay body if it is porous, and show through the enamel if the latter is not opaque.

3. Liability to hold dirt on the surface is tested by rubbing damp soot or lamp black on the surface of the glaze and then wiping off. If the glaze is not smooth, the small depressions will hold the dirt.

4. For determining the resistance of the glaze to corrosive vapor the following is suggested:

A piece of brick is placed under a bell glass, exposed to the fumes of hydrochloric acid for 24 hours. The pieces are then removed without wiping and allowed to dry, protected from the dust. A poor brick will show a white scum on its glazed surface, but a good one remains unattacked.

Glazes on fancy tiles and art wares are liable to fail under this treatment.

5. Resistance to percussion is sometimes tested with an impact machine, the brick being bedded in sand.

CHAPTER X.

ARCHITECTURAL TERRA COTTA.

Definition. The term *terra cotta*, which means baked earth, has been used in its broadest sense to include both pottery and structural objects made of burned clay and having porous body.

Architectural terra cotta, however, is a narrower term and is usually applied to those clay products employed for structural decorative work which cannot be formed by machinery. They are consequently molded by hand.

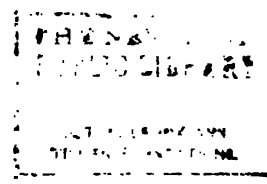
Raw Materials. Architectural terra cotta was originally made of a red-burning clay, but at the present day this practice is the exception, and most of this type of ware is produced from a mixture of several clays, all of which may be low-grade fire clays, and therefore of buff-burning color. To these there is added some grog (ground up fire-brick or other burned clay), in order to make the body easier to dry and burn. The body, after burning, is generally some shade of buff, but this is not a matter of great importance since the color does not show exteriorly, for the reason that an opaque skin of different composition from the interior hides the color of the latter.

Method of Manufacture. The manufacture of architectural terra cotta calls for considerable skill and care, and the demands of the architects as to color or form are sometimes quite severe. Moreover, the ware must come from the kiln of the proper dimensions to fit into those parts of the building for which it is designed, and for this reason the maker must know quite accurately the shrinkage of his raw materials.

In making architectural terra cotta the clay is first properly tempered and then stored in cellar bins until ready for use.

Molding is done in plaster molds, into which the clay is pressed by hand, unless the design is intricate and undercut, in which case it has to be modeled.

PLATE LII.—Terra cotta panel used in construction of State Education Building, Albany, N. Y. (Photo from Atlantic Terra Cotta Company.)



Small and simple designs can be formed in one piece, but larger objects have to be constructed of several separate pieces, which are joined together when set in the building.

After molding, the ware has to be slowly and carefully dried, subsequent to which it receives its surface layer of slip.

This consists of a mixture of clay, quartz, feldspar and other ingredients, mixed to the consistency of cream and sprayed on to the air-dried ware. It forms a dense layer in burning. The object is to form an opaque covering on the surface of the ware, which not only serves as a protective skin but also carries the decorative coloring.

Terra cotta is burned in special kilns, in which the fire gases do not come in contact with the ware, and the temperature of burning varies at different works. This signifies only that the clay used at one works burns hard at a lower temperature than that employed at another factory.

After the ware comes from the kiln, the different parts of a given design are matched together, to see if they fit properly.

Terra cotta is now made in a large number of shades and colors.

The surface slip may be of dull finish, or glazed, either matt (dull) or bright. The dull finish is often decorated so as to match or imitate different types of building stone in color and pattern. Glazed terra cotta may show either one color or a number of colors (polychrome) arranged to form a design.

The tendency in modern terra-cotta manufacture is to make smaller pieces than formerly. There is also a reduction in size of cornice blocks, which can be easily anchored to the building. Brackets are usually the largest pieces, with the exception of exterior and interior mitre pieces, which have to be made in one piece.

It is comparatively easy to make columns 6 feet long and keep them straight in burning, but they are usually cut up into sections. A fluted column requires greater care than a smooth one. Precautions have to be taken to prevent long columns from warping in the kiln and drums from spreading out on the end upon which they rest in drying and burning.

Full columns are rarely made in one piece, but are cut up in segments and joined together.

Ordinary terra-cotta pieces are usually from 12 to 18 inches in length, and vary in thickness according to the wall.

Some excellent and skilful modelling of figures, capitals, floral designs, etc., is often done.

Polychrome terra cotta, or architectural fayence, of high artistic merit is now made by several art potteries and terra-cotta works. It is rapidly finding wide favor and is extensively used for both interior and exterior decoration.

Properties of Terra Cotta. Since terra cotta is often used as a substitute for stone, its properties as compared with the latter may be mentioned.

The advantages claimed are: Less weight per cubic foot; greater durability; greater range of colors; finer lines of ornamentation; better fire resistance; cheaper cost.

The disadvantages claimed are inability of many pieces to stand hard knocks; unadapted to massive work; more costly to lay.

Terra cotta for architectural work should be hard burned but not vitrified; the different pieces should fit together well; the absorption of the body should be moderately low; it should not become discolored by soluble salts; the surface should be steel hard.

If the ware is covered with a glaze the latter should be free from cracks, crazes, pimples or holes.

In the writer's opinion architects should exercise more caution in the acceptance of glazed terra cotta, as not a few very poor jobs are to be seen in both the United States and Canada.

Testing Terra Cotta. There are few published tests of terra cotta, nor have any standard series of tests been recommended.

The ware can be tested for absorption and soluble salts. Crushing tests can also be made. A number of the latter type have been made by R. F. Grady[1] of St. Louis, and some of these are given below.

[1] American Ceramic Society, Transactions, X, p. 135; XI, p. 75; XII, p. 90.

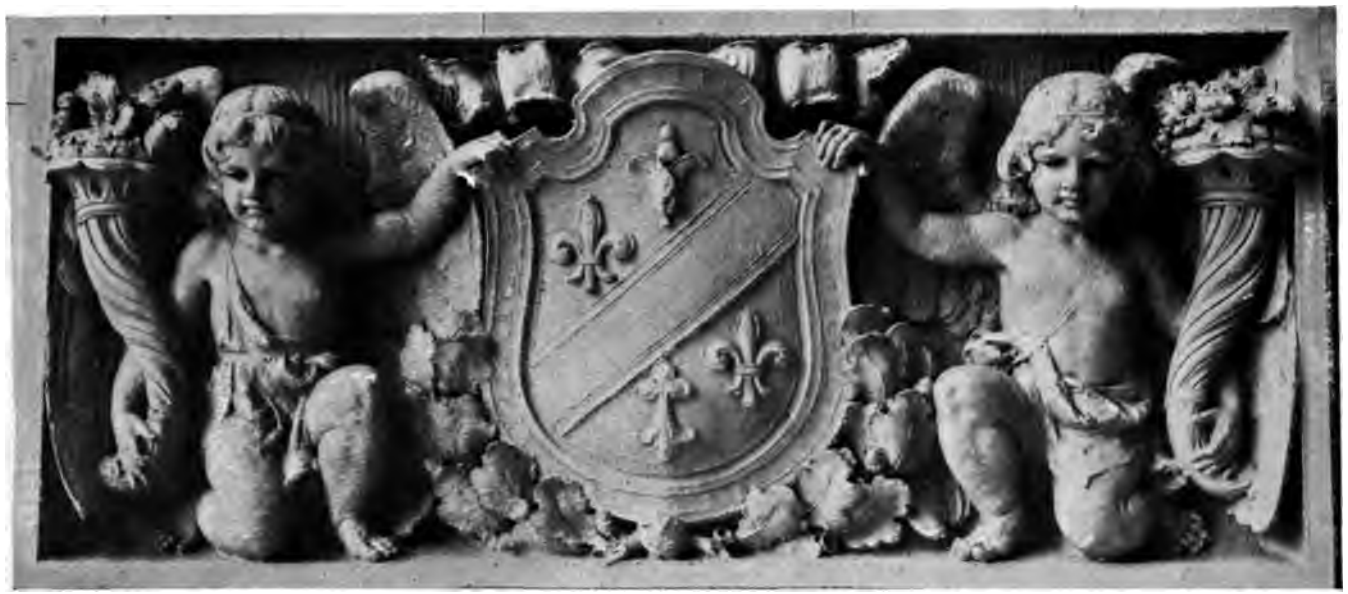


PLATE LIII. — Terra-cotta panel, Rice Hotel, Houston, Tex.
(Photo from North-western Terra Cotta Company).

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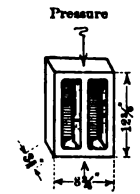
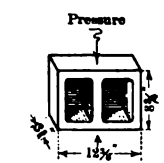
Area under compression, sq. inch.	Ultimate strength, pounds.	Pounds per sq. inch under compression.	Approximate area of cross section under compression, sq. inch.	Pounds per sq. inch cross section.	Capping.	Pressure applied as below.
31.72	67,590	2130	18.06	3742	Plaster	
31.72	68,180	2149	18.06	3775	Plaster	
31.72	58,090	1831	18.06	3216	Plaster	
31.72	63,140	1991	18.06	3496	Plaster	
31.72	63,680	2007	18.06	3526	Plaster	
31.72	66,030	2082	18.06	3656	Plaster	
44.86	84,190	1876	22.6	3725	Plaster	
44.86	90,110	2009	22.6	3987	Plaster	
44.86	94,560	2108	22.6	4184	Plaster	
44.86	100,000 +	2229	22.6	4424	Plaster	
44.86	99,410	2216	22.6	4398	Plaster	
44.86	100,000 +	2229	22.6	4424	Plaster	





Further tests made by Grady,[1] to determine the relation between absorption and crushing strength of a terra-cotta body, did not show uniform results; for while the absorption decreased with harder burning, the crushing strength did not show a steady increase.

The figures are given below, but the one series of tests cannot, of course, be considered as absolutely conclusive. The pieces tested were two-inch cubes. The temperatures below are expressed in Seger Cones, with the theoretic melting point placed after each.

Cone.	Theoretic melting point.	Absorption, per cent.	Crushing strength, lbs. per sq. in.
	Deg. C.		
04	1070	10.85	3319
02	1110	10.73	3248
1	1150	10.16	3354
2	1170	9.76	3585
3	1190	9.55	4007
4	1210	9.60	3499
5	1230	9.36	3320
6	1250	8.37	3867
6+	....	7.91	4132

In a test made by the New York Architectural Terra Cotta Company, a terra-cotta modillion, 10 inches high and with 8 inches face, was loaded with 4083 pounds of pig iron without breaking.

Terra-cotta Scum. Terra-cotta makers are often troubled with a yellowish or greenish yellow scum that appears on the surface of terra cotta, sometimes not until after placement in the building. Cases in which an entire order has been rejected because of this trouble have come to the author's notice.

The scum appears to be caused by soluble compounds of the rare element vanadium, and most terra-cotta makers have trouble in coping with the difficulty.

Fire-resisting Properties. Freitag states that "The behavior of architectural terra cotta under fire test in the Baltimore and San Francisco fires was very disappointing. Numerous

[1] American Ceramic Society, Transactions, XII, p. 90.

PLATE LIV. — Interior of Railway Exchange Building, Chicago, Ill. All glazed terra cotta except steps and floor which are marble. (Photo from Northwestern Terra Cotta Company)

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accounts, of the former fire especially, have dwelt upon the apparently excellent showing made by this material. From the street, or from a superficial examination only, many brick and terra-cotta walls appeared to be little injured, when, in fact, the terra cotta, although retaining its form, was quite destroyed. Thus, in several buildings where walls of this character seemed to have sustained but trifling injury, the adjusted fire loss and actual reconstruction told a far different story. Brick walls with terra-cotta trim were entirely replaced in the Union Trust Company's and Herald Buildings, while in the Calvert Building the adjusted loss on ornamental terra cotta was 73.5 per cent, in the Equitable Building 70 per cent and in the Maryland Trust Company's Building 75 per cent.

"The report of the National Fire Protection Association states that 'Good terra-cotta wall trim, when reasonably plain and free from ornamentation involving irregular shapes, is superior to stone but not so desirable as brick.' This carefully guarded statement on the part of the underwriters who framed that report was further justified by the showing made by architectural terra cotta in the San Francisco conflagration.

"This says:[1] 'Of the terra-cotta fronts, most were destroyed, for instance the Bullock and Jones Building. Terra-cotta brick spalled everywhere. . . . Either stone, brick or terra cotta was used around windows, and here the damage was worst. Many fronts, apparently in good order, must be removed. In the Mills Building there was hardly a window opening in which the terra cotta sills, jambs and heads were not badly cracked. From the street they had the appearance of being in good order.'"

Freitag believes that the injury by fire to architectural terra cotta is due to: "(*a*) direct flame action, (*b*) shattering due to more or less sudden changes in temperature, or (*c*) mechanical damage caused by poor construction or by the expansion of covered steel members."

"Slight damage usually results from the first and second causes, except where the material is highly ornamented, or

[1] Quoted by Freitag from Trans. Am. Soc. Civ. Engrs., LIX, p. 238.

where manufactured with too thin surfaces or dividing webs. To be efficient under fire test, architectural terra cotta should be of as plain a surface and design as possible, and with no thickness of material less than one and one-half inches."

The largest part of the damage to architectural terra cotta is said to be due to the third cause.

CHAPTER XI.

HOLLOWWARE FOR STRUCTURAL WORK AND FIREPROOFING.

UNDER this heading are included a number of hollow shapes, of varying size, form and porosity, but all having usually one or more cross webs for strengthening purposes.

Types of Hollowware. The following terms are applied to the different types:

Fireproofing. This is a general name applied to those forms used in the construction of floor arches, partitions and furring for walls, columns, girders and for other purposes in fireproof buildings. *Terra-cotta lumber* is also a general term applied to those forms of fireproofing which are comparatively soft and porous, owing to the addition of a large percentage of sawdust to the clay. The former burns off in the kiln, thus leaving the product so soft and porous that nails can be driven into it. *Hollow blocks* are forms which are used for both exterior and interior walls, in either fireproof or nonfireproof buildings. *Hollow brick* are like hollow blocks in form, but no larger than many ordinary building brick, and are much used for partitions on account of their light weight and non-conductivity for sound and heat. *Book tiles* are flat, hollow tiles, which have two segmental edges. They resemble a book in section. *Furring blocks* is a name applied to slabs which are placed against exterior walls to secure insulation against dampness, heat, cold and sound.

Raw Materials and Manufacture. Hollowware is made from either red or buff-burning clays or shales, or a mixture of these with fire clay, usually of low grade. The material is molded in a stiff-mud machine, dried by artificial heat in tunnels and burned in some form of permanent kiln, usually at a moderate temperature, and not as a rule to the vitrifying point.

Defects which the ware may show are cracks, formed in drying and burning, and blisters or pimples, the latter caused by lumps of clay, pyrite, or siderite. The color, as already stated, is usually red, but unless the product is a hollow block for front walls the color is not a matter of great importance. The absorption varies with the hardness of burning, and quantity of ground brick, sand, or sawdust added.

Fireproofing. The object of fireproofing is not only to protect the inclosed metal parts of the building from the direct action of the flames in case of fire, but the hollow spaces also serve as nonconductors of heat. The material should not be vitrified. It is sometimes made from shale or common clay, or a mixture of these with low-grade fire clay.

There exists a diversity of opinion regarding the relative merits of porous and hard-burned fireproofing, especially when used for floor arches set in between the I-beams.

Porous fireproofing, it is argued, is easily cut and nails or screws can be driven into it. It is also thought to show a better resistance to suddenly applied loads.

Hard-burned fireproofing is not readily cut, but must be broken. It is more brittle than the porous and therefore more liable to fail under shocks.

An intermediate type, known as semi-porous is regarded by many as the best.

Under static loads the hard-burned fireproofing is said to be stronger than the porous, where equal sectional areas are compared, but this deficiency on the part of the porous can be made up by increasing the thickness of the webs.

In making an arch for flooring, three shapes of blocks are necessary, viz: the skewback, key, and lengtheners, fillers or intermediates.

The blocks used for floor arches may be of two types of construction, viz., end or side.

In the end-construction arches the blocks are set end to end, so that the cells run at right angles to the beams, or from beam web to beam web.

The arch pressure is therefore against the ends of the blocks,

PLATE LV. — Flat arch of fireproofing.

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and since hollow tiles show greater strength under end compression than side compression, an end-construction arch will develop about 50 per cent more strength, for the same weight, than a side-construction one. This, of course, is on the assumption that the arch is properly set.

In the side-construction arch, the lengtheners and key are set side by side, and the openings run parallel with the girders on which the base of the arch rests.

Side-construction skewbacks may be: (1) plain, or without any provision for protecting the beam flange; (2) lipped, or with a protecting lip attached (Plate LV); (3) soffited, that is, with a bevel at the bottom of the skewback to hold the soffit tile in place under the beam.

Lipped skews are less used than formerly, as the lip may be warped during drying and burning, or be broken during erection.

End-construction lengtheners are now more widely used than side-construction ones.

A lengthener in end construction is usually 12 inches wide and 12 inches long, while the interior webs vary with the depth and required strength. Six-inch blocks can be made without interior horizontal webs.

"For semi-porous blocks[1] the usual thickness of the outer shells is $\frac{3}{4}$ inch, and for the interior webs about 1 inch. The cells should preferably be not over $3\frac{1}{2}$ inches in either direction.

"Both end- and side-construction keys are used in end-construction arches, the former being generally used when the span requires a key over 6 inches wide, and the latter for 6 inches or less.

"The objections to end-construction arches are, — first, that the blocks cannot be made to break joint, — second, that a true end-bearing and mortar joint is more difficult to obtain than with side-construction blocks, — and third, that more mortar must be used on account of the waste in the cells. Objections one and two can be disregarded in view of the excess strength obtained through using the end-construction method, while objection three is of small consequence."

[1] Freitag, *l. c.*, p. 557.

The various depths of arch blocks, weights per square foot of arches, and permissible spans for standard side-construction arches are as follows: [1]

Depth of arch, inches.	Weight, pounds per square foot.	Spans allowable between I-beams.	
		Arch set flat, feet and inches.	Set with slight camber, feet and inches.
6	24–26	4–0	4–6
7	26–28	4–6	5–6
8	27–32	5–0	6–0
9	29–36	5–6	7–0
10	33–38	6–6	7–6
12	37–44	7–0	8–6

NOTE. — The heavier weights are the ones commonly used.

The weights of standard end-construction arches and permissible span are given as below.

Depth of arch, inches.	Weight, pounds per square foot.	Spans allowable between I-beams.	
		Arch set flat, feet and inches.	Set with slight camber, feet and inches.
6	20–26	4–6	5–0
7	22–29	5–0	5–9
8	24–32	5–6	6–6
9	26–36	6–0	7–0
10	28–38	6–6	7–6
12	30–44	7–6	9–0
15	37–50	9–0	10–0

Furring Blocks. These are much used in refrigerator or cold-storage buildings, and other places where it is necessary to preserve a uniform temperature.

In small structures, as stores and dwellings, a single-thickness block, with a 1-inch or 2-inch air space may be used.

Blocks 12 by 16 by 2 inches weigh 8 pounds per square foot. Double-thickness furring blocks are made from 3 to 6 inches thick.

Hollow Block and Brick. The use of hollow block as a substitute for stone or brick for ordinary work of construction of

[1] Freitag, *l. c.*, p. 554.

houses as well as large buildings is increasing rapidly, especially in the central states.

Hollow blocks employed for exterior walls are often vitrified or nearly so, and the advantages claimed for them over common brick are: (1) Lighter weight per cubic foot of wall; (2) Sufficient strength to insure a large safety factor; (3) Much less clay required; (4) Lower transportation costs for a given bulk because of less weight; (5) Full protection against dampness and temperature; (6) Less labor required to lay in wall.

The surface is usually smooth, or ribbed to hold the mortar, but for ornamental purposes the block can be made with one decorated surface.

A number of different shapes and sizes of hollow blocks are made, and while the majority of them agree in being 12 inches long, the other two dimensions may vary. Thus, of the blocks which are 12 inches long, the other dimensions may be 6 by 3 inches, 6 by 4 inches, 6 by 5 inches, 6 by 6 inches, 6 by 7 inches, etc., or perhaps 3 by 8 inches, or 3 by 12 inches, etc.

A block 4 by 8 by 16 inches usually weighs 20 pounds; one 8 by 8 by 16 inches, 34 pounds; and a cubic foot of hollow block averages 40 pounds.

Hollow blocks when used for partitions are not necessarily of vitrified character. Hollow brick employed for partitions are commonly more or less porous. They are commonly made of a red-burning clay, but even cream-burning calcareous clays have been employed for this purpose.

In recent years a mixture of clay and diatomaceous earth [1] has been made into partition bricks in Virginia and California.

Freitag [2] gives the following as essential requirements for a fireproof partition: (1) Architectural service; (2) Fire-resisting service; (3) Heat-retarding qualities; (4) Stability against shock, water streams, etc.; (5) Deadening qualities to prevent transmission of sound.

The square blocks for partitions are commonly 12 by 12 inches for the body of the wall, and 6 by 12 inches, and 8 by 12 inches for the end spaces or tops of the partitions.

[1] Usually, though incorrectly, called infusorial earth. [2] Loc. cit., p. 236.

For brick-shaped blocks, the sizes made in semi-porous terra cotta are 6 by 8 by 12 inches, 6 by 12 by 12 inches, 4 by 12 by 12 inches, 4 by 8 by 12 inches, 3 by 12 by 12 inches, and 2 by 8 by 12 inches. Porous partition blocks may run 4 by 8 by 12 inches, 4 by 12 by 12 inches, 6 by 8 by 12 inches, 6 by 12 by 12 inches, 2 by 12 by 12 inches, and 2 by 8 by 12 inches.

Freitag[1] gives the weights per square foot of tile partitions, without plaster, as being on the average about as follows:

	2-in.	3-in.	4-in.	5-in.	6-in.
	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
Semi-porous tile	12	15	16	18	24
Porous tile	14	17	18	20	26

If plastered on both sides, add 10 pounds per square foot to the above.

Tests of Hollow Blocks. A number of scattered tests of this class of ware have been published.

The following tests of hollow blocks are given by the Iowa Geological Survey:[2]

BLOCKS EMBEDDED IN PLASTER TOP AND BOTTOM.

No.	Approximate dimensions.	Position.	Crushing strength,[1] tons per square foot.
1	4×8×12	Flatwise	78.1+
	4×8×12	Endwise	230.8
	4×8×12	Edgewise	171.5+
2	4×8×12	Flatwise	64.0
	4×8×12	Edgewise	59.6
	5×5×12	Flatwise	39.1
	4×4×12	Flatwise	56.5
3	5×8×12	Flatwise	30.2
	5×8×12	Edgewise	65.0
4	5×8×12	Flatwise	47.0
	5×8×12	Endwise	131.0
	5×8×12	Edgewise	59.9
5	5×8×16	Flatwise	49.0
	5×8×16	Flatwise	55.5+
	8×8×16	Flatwise	58.0

[1] *l. c.*, p. 399.

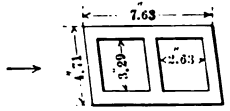
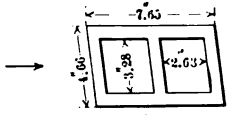
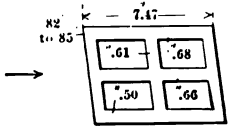
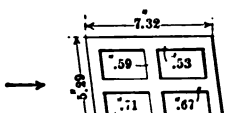
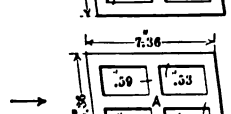
[2] Iowa Geol. Surv., XIV, p. 600, 1904.

Architects usually allow from five to ten tons per square foot pressure on brick masonry. Even with this the hollow brick show a large safety factor.

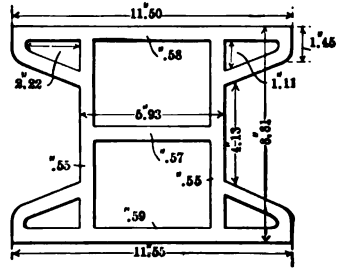
In another test[1] it was found that blocks 8 by 8 by 16 inches developed an ultimate strength of 2500 pounds per square inch, in center web blocks, and 1969 pounds per square inch on gross area; and 6000 pounds per square inch on net area in corner blocks.

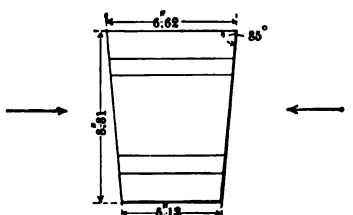
In the Report on Tests of Metals, etc., for 1895, published by the War Department, there are given a number of tests of fireproofing, from which the following tests are extracted.

[1] Brickbuilder, Vol. XV, p. 164, 1908; British Clayworker Suppl., XV, p. LII, 1906.

End view.	Length.	Color.	Weight.		Sectional area.		First crack.	Ultimate strength.		
					Gross.	Net.		Total.	Per square inch on gross section.	Per square inch on net section.
			pounds.	ounces.	sq. in.	sq. in.	pounds.	pounds.	pounds.	pounds.
	11.18	Red	15	1	52.66	15.88	35,800	55,860	1061	3518
	11.18	Red	15	0	52.10	15.43	38,200	65,510	1257	4246
	11.16	Dark brown	18	1	59.82	20.53	34,900	93,580	1564	4558
	10.98	Dark brown	17	9	58.08	20.97	42,000	104,800	1804	4998
	10.82	Light brown	17	10	57.99	20.99	34,000 at A.	91,600	1581	4364

End view	Length.	Color.	Weight.		Sectional area.		Ultimate strength.			
			pounds	ounces.	Gross.	Net.	First crack.	Total.	Per square inch on gross section.	Per square inch on net section.
					sq. in.	sq. in.	pounds.	pounds.	pounds.	pounds.
	10.92	Red	17	9	80.04	.....	119,000 at A.	157,900	1973	.....
	10.94	Red	17	12	79.97	.....	107,000	142,300	1779	.....
	10.94	Red	17	8½	80.08	.....	112,000 at A.	133,100	1662	.....



Side view.	Description.	Color.	Weight.		Net sectional area.	First crack.	Ultimate strength.	
							Total.	Per square inch.
			pounds.	ounces.	sq. in.	pounds.	pounds.	pounds.
	9″ end-pressure arch No. 6 key tile	Dark buff	12	9	34.33	102,800	102,800	2994

From a series of tests of crushing strength and absorption made by V. G. Marini,[1] the latter has suggested some tentative specifications for hollow clay tile building blocks.

Some of the tile were built up in columns of different dimensions, and with the tile laid in different positions in the various columns, these being then tested for their crushing strength. Other tile were tested singly.

From the results of these tests it was noticed that in the case of those tile having an absorption of less than 12 per cent, and with the vertical webs spaced not more than 4 inches apart, centre to centre, and with a web thickness of at least 20 per cent of the height, the blocks being placed so that the vertical webs were directly over each other, no single tile or column failed under a less load than 3465 pounds per square inch of the vertical web section.

The following specifications are suggested for hollow clay tile, the tile to be laid with the voids horizontal.

(1) *Character of Body.* Tile to be made of shale or fire clay, or any clay that will burn to a good dense body without undue warping or checking, and must be burned to such a degree of hardness that they will not absorb more than 12 per cent moisture.

(2) *Webs.* Vertical webs should be spaced not more than 4 inches apart, centre to centre, and should have a thickness of at least 20 per cent of their height.

(3) *Bedding.* To secure thorough bedding, tile should be so constructed as to preclude mortar beds of more than $4\frac{1}{2}$ inches (same as brickwork) in width, and should be laid with broken joints and be thoroughly bedded and bonded.

(4) *Quality.* Tile should be true and free from injurious checks and cracks.

(5) *Position in Wall.* Tile should be so laid in wall that the vertical webs are in vertical alignment with the vertical webs of the adjacent tiles below.

(6) *Loads.* Tile walls should be loaded with not more than 200 pounds per square inch of vertical web section.

[1] The Engineering News, Vol. 67, p. 248.

(7) *Thickness of Walls.* Permissible thickness of load same as for common brick.

(8) *Joist or Bearing.* Where joists or beams are set in walls, they should have a bearing extending over at least two of the vertical webs.

Fire Tests. Since certain forms of hollow blocks are used for combined fireproofing and structural purposes, a properly made fire test is of value.

In the test of fireproof floor construction recommended by the American Society for Testing Materials, a standard test structure is used, with the hollow blocks built into a floor. A working load of 150 pounds per square inch is distributed over the floor, without arching effect, and is carried by the floor during the test.

The test must be made within forty days after construction, and artificial drying is allowed.

The test itself will consist in subjecting the floor to the continuous heat of a wood fire averaging not less than 1700° F. for 4 hours. The temperature shall be measured by means of a standard pyrometer at two points at least, and readings taken every two minutes. At the end of the heat test the floor is cooled by a stream of water thrown on its under surface. A load of 600 pounds per square inch is then distributed over the floor. The test shall not be regarded as successful unless the following conditions are noticed: No fire or smoke shall pass the floor during the fire test; the floor must safely sustain the loads prescribed; the permanent deflection must not exceed $\frac{1}{8}$ inch for each foot of span in either slab or beam.

In a test made by Professor I. H. Woolson,[1] a large chamber with brick walls was used, and this was floored over on top with an arch of six-inch hollow tile covered by four inches of cement.

This was loaded to 270 pounds pressure per square inch and fire built underneath, burning four hours with an average temperature of 1700° F. While still red hot a stream of water was played on under side of floor for ten minutes at a pressure of

[1] Brickbuilder, XIV, p. 33, 1905.

from 75 to 80 pounds. The cement spalled off, but the tile showed no cracking, and the maximum deflection determined by careful measurements was 0.4 inch sinking of floor.

Freitag[1] believes that the behavior of fireproofing in a fire is due not alone to the character of the material itself, but that contributing factors are the conditions of the test, details of construction, etc.

He concludes that " porous or even semi-porous tile can, and generally does, withstand any reasonable fire and water test, provided that the material is of sufficient thickness and is used in an intelligent manner."

In comparing hard-burned and porous terra cotta, Freitag further says:

" *Hard-burned terra cotta* as a heat insulator depends for value entirely upon its cellular structure, protection being afforded only by the non-heat-conducting air spaces. The material itself conducts heat much more readily than the porous kind. To be efficient, therefore, the air spaces in hard-burned tile must be of adequate size and number to insulate the material to be protected. When cooled by water, sudden contraction is liable to occur, thereby cracking the blocks. If made of a good refractory clay, blocks with two or more air spaces are very liable to have the outer webs destroyed under this action, as was well illustrated by the hard-tile floor arches in the first Horne Store Building of Chicago. This was due to the inability of the material to withstand the inequalities of expansion and contraction caused by the heating of one side of the arches only. The blocks usually break first in the corners, because the strain is greatest there, and the tile weakest. The strain is greatest in the corners because the expansion of the one side tends to shear it from the adjoining sides, and it is weakest in the corners because if there is any initial stress in the material, it would more naturally occur there than elsewhere.

"Even if not cooled with water, other fires have shown that hard-burned terra cotta will crack and fall to pieces under severe heat alone.

[1] " Fire Prevention and Fire Protection," p. 236.

"*Porous terra cotta* is non-heat-conducting itself, without reference to its form. It is made in solid as well as in hollow forms. The best products of a porous nature have resisted fire and water far better than the best hard tile. For column and girder protections, where the blocks do not carry loads, the porous material is very generally used, but in floor construction many architects prefer to use the hard-burned variety on account of its greater strength and cheaper price.

"*Semi-porous terra cotta* is largely used. It is stronger than porous tile and less liable to crack than hard tile."

CHAPTER XII.

ROOFING TILE.[1]

ALTHOUGH widely used for many years abroad, the employment of roofing tile in the United States has not been so extensive. The industry, however, has shown a very healthy growth.

The standard roofing tile which are for exterior covering and decoration are made in the following shapes: (1) Shingle; (2) Mission, Mexican or Roman, called also Old Spanish and Normal; (3) Spanish or S tile; (4) Interlocking.

Shingle Tile. These are perfectly flat, and laid on the roof in the same manner as slate. They are regarded by many as plain and monotonous, although an attempt has been made to overcome this by making them with strong vertical ridges and valleys.

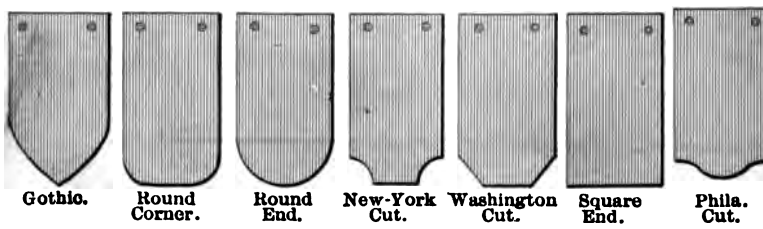


Fig. 14. — Different styles of shingle tile.

A shingle tile which is flat will, when properly laid, make a water-tight roof, but the main objection to it is the weight, which is 200 to 400 pounds more per square than the Spanish or interlocking. It takes about 400 tile to cover a square, and the time required for laying shingle tile is longer than in the case of other types.

One shingle tile made at Huntington, W. Va., measures 6 by $13\frac{1}{2}$ by $\frac{3}{8}$ inches, weighs 1100 pounds per square, 436 tile being required, laid with $5\frac{1}{2}$ inches to the weather.

[1] An excellent report on the properties and manufacture of roofing tile has been issued by the Ohio Geol. Surv., 4th Ser., Bull. 11.

Those made at Parkersburg, W. Va., weigh about 1200 pounds per square for a 7 by $14\frac{1}{4}$-inch tile, laid 350 tile per square, with 6 inches to the weather.

Shingle tile may have either square or rounded edges, the latter being more artistic and easier to make. It is also claimed that vertical lines are accentuated more with round-edged tile.

Old Spanish, Normal, Mexican, Mission or Roman Tile. These names are all applied to a roofing tile of semicircular cross section, slightly smaller at one end than the other, so that they can be laid overlapping. They are laid with the concave and convex sides up alternately, so that one straddles two others.

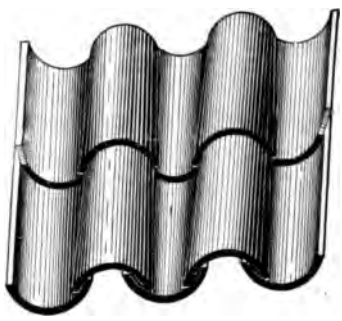


Fig. 15. — Old Spanish or Mission Tile. (Akron Roofing Tile Company.)

Sometimes a tile of this style is laid in connection with a pan tile; that is, a flat tile with upturned edges.

The use of these Old Spanish tile is somewhat restricted in the United States, but they have been much used in the southwest to accompany the mission style of architecture.

The Old Spanish tile roof is not water-tight, it has to be laid in elastic cement.

The ordinary size is 6 by 13 by $\frac{3}{8}$ inches, and the weight of tiles $\frac{3}{8}$ inch thick is 1100 pounds per square; $\frac{1}{2}$ inch thick, 1200 pounds.

Modern Spanish or S Tiles. These have been made to overcome technical defects of preceding. Their section in one case represents a letter S, or in the other a combination of Old Spanish and pan tile made in one piece. The objection to these tile is that, like the preceding, they must be laid in cement.

However, in spite of these objections, they are likely to be widely used, because they can be made cheaper than an interlocking Spanish tile and are as good from an architectural standpoint.

Interlocking Spanish tile are made with side and end locks, or tongues and grooves on the upper surface of the tile which intermesh with corresponding grooves and tongues on the lower surface of the next ones. This gives a water-tight roof without cement. They cost more.

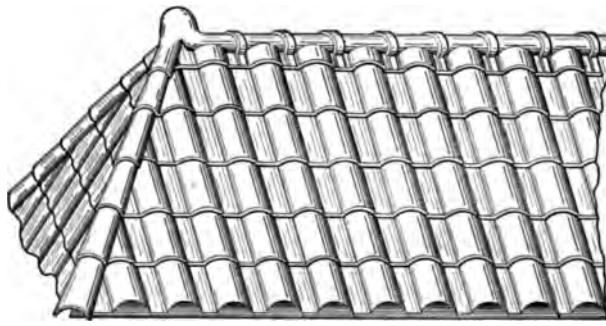


Fig. 16. — Section of roof showing modern Spanish tile, cresting, hip rolls and finials. (Akron Roofing Tile Company.)

The common Spanish S tile are usually made on auger machine. They are 11 inches wide and 12 inches long, with extreme height of roll of 3 inches, and weigh 800 to 900 pounds per square.

The interlocking Spanish look like common Spanish tiles, and while they have side and end locks, these do not show on roof. They are usually 9 by 12 inches, and weigh about 850 pounds per square.

Interlocking Tile. These are constructed with tongues and grooves on the edges and ends, which fit into each other and lock the tile together.

The normal interlocking tile are usually of rectangular outline, and varying size, but 9 by 16 inches are common dimensions.

They overlap about two inches on all sides, and about 135 are required to a square. The weight of this quantity is from 800 to 850 pounds.

Interlocking shingle tile are usually 9 by 13 by $\frac{1}{2}$ inches, requiring about 190 per square, with a weight of 800 to 900 pounds.

Interlocking Spanish tiles look like the common Spanish tiles. They have side and end locks, but these do not show on the roof.

They are commonly 9 by 12 inches in size, and weigh about 850 pounds to the square.

Materials and Manufacture. The crushing and preparation of the clay are done by methods which are, in general, similar to those employed for pressed-brick manufacture, but the grinding and preparation of the clay are more carefully done.

Shingle and Spanish tile (except the Old Spanish) can be made by forcing a ribbon of clay from an auger machine, but interlocking tile are manufactured by repressing slabs of the tempered clay in a special form of machine.

The tile are then carefully dried and burned. If the setting of the tile in the kiln and the burning are not properly done, there is great liability to loss from warping, cracking and checking.

A softer burned tile costs less to manufacture and is a better non-conductor of heat, as well as providing a cooler roof.

Owing to our more severe winters, American tile should be fairly hard burned.

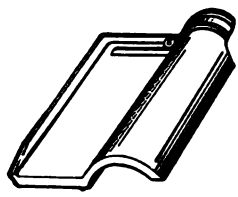
Porosity of Roofing Tile. There exists a diversity of opinions regarding the relative merits of porous and vitrified tile. Most French and German ones are porous; so, too, are some American ones.

Tests made by H. A. Wheeler[1] show that the absorption of well-tested American roofing tile ranges from 1 to 21 per cent after 24 hours' immersion, but that there is no fixed relation between absorption and frost resistance.

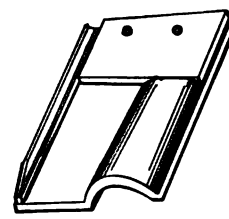
These absorption percentages are shown in the accompanying table (p. 355).

The objections urged against a porous tile are: 1. That they lack frost resistance. 2. They absorb dirt and become old and unsightly looking in a short time. 3. That high absorption of water increases weight of roof, but if 25 per cent is absorbed and this overloads the roof it means too small a safety factor. 4. They may contain soluble salts, which sometimes cause the tile to disintegrate. The objections urged against a vitrified tile are that it tends to condense moisture on its under surface, if laid with the under surface exposed. But vitrified tile are not

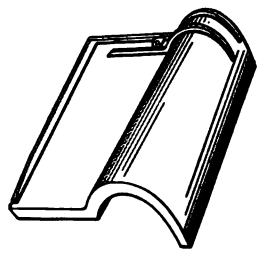
[1] American Ceramic Society, Transactions, VIII, p. 154, 1906.



Regular Tile

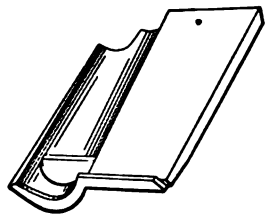


Flat Top
Flattened tile for finishing course.

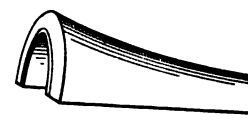


Right Gable Rake
Depth of flange below top of sheathing, one inch.
Weight per foot, 6 pounds.

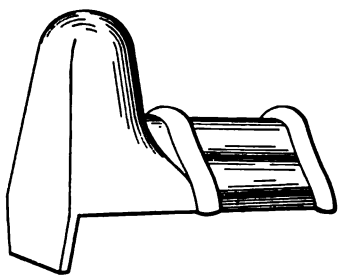
End Band
Same length as regular tile; roll only.
Used for flashing purposes.



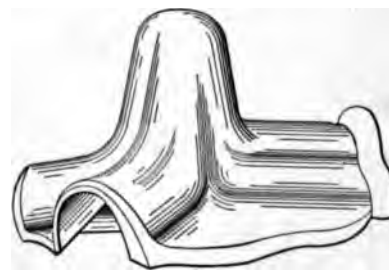
Closed Eave.
Inverted tile showing fixed closure.



Hip Roll.



Gable Terminal.



Two-way Terminal.

PLATE LVI.—Regular and special shapes of Spanish interlocking tile.
(Ludovici Roofing Tile Company.)

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ASTOR, LENOX AND
TILDEN FOUNDATIONS

ABSORPTION OF AMERICAN ROOFING TILE (Wheeler).

Designation of tile.	Per cent of water absorbed in					Remarks.
	¼ hour.	1 hour.	10 hours.	24 hours.	48 hours.	
A	0.1 to 0.2	0.2 to 0.7	0.4 to 1.4	0.4 to 1.8	0.8 to 2.7	Very dark red, vitrified.
B	.....	0.1 to 3.2	0.1 to 3.6	0.3 to 3.7	0.3 to 3.8	Very dark red, vitrified.
B–1	.....	0.3 to 1.5	0.6 to 2.4	0.8 to 2.6	1.0 to 2.8	Dark gray, hard burned.
C	12.0	12.0 to 12.2	12.5 to 12.6	12.7 to 12.8	13.2 to 13.4	Light red, burnt medium hard.
D	0.7	0.9	2.2	2.8	3.1	Dark red, hard burned and glazed
E	5.4	5.6	5.7	5.9	6.0	Medium red, well burned.
E–1	.....	5.3 to 5.8	5.5 to 6.3	5.5 to 6.3	5.6 to 6.4	Brown, hard burned.
F	20.0	20.1	20.8	21.5	21.5	Light red, soft burned.
G	4.0	4.7	5.5	6.0	6.4	Very dark red, hard burned.
H	0.1	0.3	0.3	0.3	0.3	Very dark red, vitrified.
H–1	1.4 to 2.4	2.1 to 3.8	2.2 to 4.8	2.3 to 4.8	2.4 to 4.9	Dark red, hard burned.
H–2	.....	6.7	6.8	7.1	7.2	Medium red.
H–3	6.5 to 6.8	6.5 to 6.8	6.9 to 7.1	6.9 to 7.1	7.1 to 7.4	Light red, soft burned.
H–4	11.9 to 14.0	11.9 to 14.0	12.2 to 14.4	12.2 to 14.3	12.5 to 14.4	Very light red, very soft burned.
H–5	8.4 to 8.7	8.4 to 8.7	8.5 to 8.8	8.5 to 8.8	8.6 to 8.9	Buff, medium burned.

necessarily more durable than porous ones and much may depend on the size of the pores. Thus, it is argued that large pores, with thin walls between, do not resist the internal pressure of freezing water as well as evenly distributed, thicker walled, smaller pores.

Some claim that porous tile should not be laid against brickwork, as they absorb the moisture from the brick backing.

There has been some discussion as to the value of glazing roofing tile, and it may be said, by way of preface, that where such a coat is given to the tile for the purpose of covering up certain bad features or prolonging its life the practice is a very bad one.

On the other hand, if the tile is coated for the purpose of adding to its architectural beauty, then the object is a praiseworthy one. The last, however, opens up a great opportunity of which American architects have as yet taken very little advantage.

But, whatever the reason for applying it, the glaze should be durable.

Roofing tile may be covered with either a slip or a true glaze.

The slip is usually a natural clay which in burning becomes converted to an impervious coat that may be either vitrified or dull. It may be used to give the surface of the tile either a better color, or a cleaner and smoother surface.

Where a roofing tile is made from a clay that burns light pink, buff or greenish color, it is necessary to use a slip to hide the unsightly color of the body. This practice is objectionable, for if the surface of the ware is chipped the body color becomes exposed. A tile with much scum does not take a slip well, and the latter scales off on freezing.

Slips could be artificially colored and afford the architect excellent opportunity for polychrome design, which is becoming of such importance in modern terra-cotta work. Little or none of this is done in the United States.

The glazes used on roofing tile may be either matt or bright. The former are mostly used, the latter being objectionable because of the strong light reflection from them.

The relative advantages of slip and glazed tile include the following.

A B

PLATE LVII, Fig. 1. — Interlocking tile showing obverse (A) and reverse (B) side. (U. S. Roofing Tile Co.)

PLATE LVII, Fig. 2. — Molding 30-inch sewer pipe in pipe press.

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Slip coats are easier to produce and subject to fewer defects than glazes.

A slip is thought by some to prove more durable on a porous tile than a glaze.

Slip coatings, being duller than even a matt glaze, cause the minimum of reflection.

Glazed tiles possess an impervious surface, which slip-coated tiles do not, hence are less liable to discolor with soot or dirty water. A glazed tile can be scrubbed clean easier than a slip-coated one.

A glaze, it is true, may keep water out of a porous tile body, but if the latter is glazed only on the upper surface it may absorb moisture from the under side.

Requisite Characters of Roofing Tile. The following may be tentatively cited: 1. Hard body. 2. Low absorption, say, under 10 per cent. 3. Freedom from warping. 4. Absence of soluble salts. 5. Good ring when struck. 6. Frost resistance.

Tests of Roofing Tile. It is doubtful if any are made even by engineers or architects, however important they may be; indeed, the main selling requirement very often and unfortunately is color and shape. The following would seem to be important tests.

1. *Frost Resistance.* Vitrified tile should rate high on this test.

2. *Soluble Salts.* These may be present in porous tile, and if present in sufficient quantity have been known to cause serious disintegration of the tile.

3. *Transverse Strength.* Some advocate a cross-breaking test.

4. *Permeability Test.* This may be carried out as follows: Paint the tile on all faces, except one, and a portion of the opposite one, with a waterproof shellac or varnish. The partially covered face is then fitted with a glass tube 8 inches high and $1\frac{3}{8}$ inches in diameter, and fastened with a little cement. Keep this cylinder filled with water to a constant level, adding water from time to time as it is absorbed by the tile. The time required for the water to pass through to the lower side is measured.

But, after all, the actual selling requirements are often color and shape, which are largely matters of personal taste of the architect.

The slow absorption of roofing tile in this country has been due to the excessive cost, which ranges from $8.00 to $50.00 per square, depending on pattern, whether glazed or not, and other factors. They have also had to compete with other forms of roof covering, such as wood shingles, slate, metal roofing, asbestos, slabs, etc.

Miscellaneous Clay Slabs, used for Roofing Purposes. In addition to the regular roofing tile, book tiles are sometimes employed. They rest on tee irons, and are sometimes used for a pitch roof and covered with slate. An objection raised against them is that they lack strength against shock and load.

Another form of product sometimes used on roofs is a rabbeted block having rabbeted edges on two sides, to permit the block to set down between the tee irons on which it rests. These blocks may be either solid or hollow, and made of either porous or hard burned material. They commonly have a width of 12 inches, and a length of 10 to 24 inches. The common thicknesses are 2, $2\frac{1}{2}$, 3 and 4 inches. The 2-inch blocks are said to weigh about 12 pounds per square foot; the 3-inch, 14 pounds; and the 4-inch, 18 pounds.

Quarry tile, viz., red burning, square or rectangular slabs, $\frac{3}{4}$ to 1 inch in thickness, are often used, especially for flat roofs, which serve for gardens or are continually being walked over. They are sometimes salt glazed. These quarries sell for about $18.00 to $30.00 per 1000 at New York.

Special Shapes. The body of a roof is covered with stock tile, but there are many different shapes made which are employed for trimmings, and to connect different parts of the roof surface which do not agree in slope or continuity.

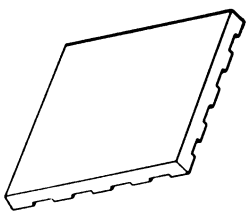

Fig. 17. — Quarry tile.

The following shapes may be mentioned:

Hip and Valley Tile. These are tile cut to fit the angles of the hips or valleys. Most tiles have to

be cut in their unburned condition, but soft tile can sometimes be cut on the job. Each hip or valley requires both "lefts" and "rights." This work, done at the factory, is charged for by the running foot.

"Closed" Hip and Valley Tile. These have a closed end to prevent snow or rain from blowing up underneath them.

Ridge and Eave Tile. Spanish and interlocking tile need a special starting tile at eave line and a finishing tile at ridge, to make a tight roof and one of good appearance. The eave tile has a closed end and is made in a press with special mold. Ridge tile differ from the regular ones, in having the upper half flattened to a plane, which rests on the sheathing boards, and has its upper edge covered by a finishing tile. The ridge tile are molded in presses.

Hip Rolls and Cresting. These are pieces of curved or other shape to fit over the ridges and hips, and make the roof weather-tight. They are sometimes of very ornamental character. The molding is done by hand or machine power, usually in plaster dies.

Hip Roll Starter. This is a closed-end tile placed at the lower end of the hip of the roof, and can be made quite ornamental in its character.

Finials. These are ornamental pieces used for finishing off the joining of the ridge line with the hips, ridge line at gables, or top of a tower. They are often highly ornamental and are usually modelled by hand.

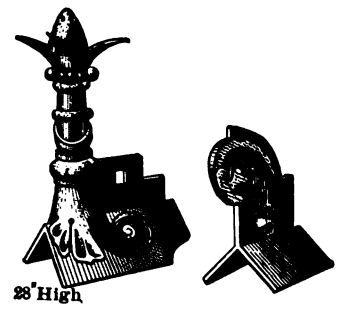

Fig. 18. — Finials for tile roof. (Akron Roofing Tile Co.)

Graduated or Tower Tile. Special shapes are necessary to fit the converging lines of a tower with pyramidal or dome-shaped roof, for it will be readily understood that as we go from the bottom to the top of such a tower the tiles diminish in width.

The rates at which the tiles diminish in width are quite different. Thus, those made for a ten-foot tower cannot be used for a twenty-five foot tower. This means that new molds and dies

must be made for almost every job. Tiles from a fourteen-foot tower can sometimes be shifted to a fifteen or sixteen-foot one, this being more easily done with Spanish tiles than with interlocking ones.

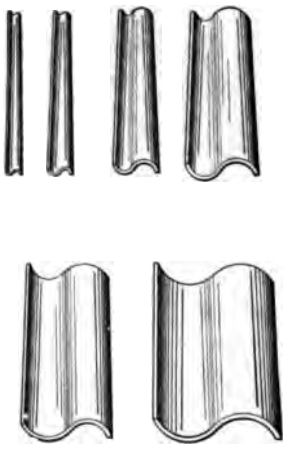

Fig. 19. — Graduated tower tile. Spanish pattern.

CHAPTER XIII

WALL AND FLOOR TILE.

TILE for interior work have been used since an early date, first in the far East, later on in Europe, their combined use for beauty, durable linings and clean surface being well recognized. Though used first in the Western countries during the twentieth century mainly for bathrooms, the rich decorative effects producible have given them a more extended field of usefulness in mantels, vestibules and other locations.

Tile can be divided into two groups, floor tile and wall tile. The former are hard burned, dense (sometimes nearly non-absorbent) and not usually glazed. The latter are quite absorbent and covered with some sort of glaze.

Manufacture of Wall Tile. Wall tile may be made of clay alone, or of a mixture of clays, flint and feldspar. Those with a white body are always of this character.

The raw materials are first purified [1] by mixing with water to a thin cream, and then straining through a silk screen of about 120 meshes to the linear inch. This is then run into filter presses and the water squeezed out. If plastic tile are made the clay, after some kneading, is ready for use, but in making dust-pressed tile, — and the bulk of modern tile are such, — the clay has to be dried, crushed to powder and steamed in order to render it slightly moist. This powdered moist clay is stored until used. The tile are formed in a tile press, which consists essentially of a steel box, with rising bottom, and a screw plunger. Its action is similar to that of a dry-press brick machine, but the shape of the tile is governed by that of the plunger or bottom of the box, and embossments can be made by shaping these to the required

[1] Wall tile made by the plastic process are sometimes made from unwashed clays.

design. Thus, moldings and other ornamental patterns are produced or a tile with decoration in relief is pressed.

The tile after pressing are set in saggers or fire-clay boxes, which are piled one upon another, thus protecting their contents from the action of the flames. After burning at the proper temperature, the tile are sorted and the glaze applied. Transparent glazes are mostly mixtures of silicate of lead, lime, potash and alumina, the mixture being ground in water to form a thin cream, in which the face of the tile is dipped.

Coloring matter, if added, is introduced in the form of metallic oxides, cobalt for blue, copper for green, iron for yellow and light brown, and manganese for dark brown, or by mingling these a variety of shades is obtainable. The flowing of the glaze in the second firing, which the tile now receives, may cause a variation in its thickness, resulting in lighter and darker tones.

Matt or dull glazes are of different composition and manipulation, and are much used now. They are colored in the same way as the clear glazes, but the texture depends on a thick coat of the material being applied to the tile, which also makes possible certain schemes of decoration not possible in bright glazes. Matt glazes are applied by dipping or with a brush. Some wondrous effects in colored glazes and crystalline glazes have been produced by modern manufacturers, both in the United States and Europe.

Dust-pressed tile are easily made, and quite straight, but on this account they are thought by many to exhibit a hard and unsympathetic surface, and hence many prefer the plastic tile, which permit a freer treatment of the clay.

These plastic tile are molded from soft clay, with some non-plastic materials as ground burned clay added. They are formed by hand pressure in plaster molds, these being larger than the size desired in the tile to allow for shrinkage in burning.

If the surface is to be embossed it can be done in the molding, by having the inner surface of the mold bear the embossment in reverse, or the tile, after drying sufficiently to shrink away from

the mold can be removed and the modeled embossment worked out by hand. Plastic tile are not always glazed.

Glazes should be free from blisters, bubbles, or holes, and should not crack or "craze." The latter may not appear at once. Moreover, even if the tile is free from "crazes" when placed in the wall, these may be caused by the cement in which the tile is laid, or by faulty composition of the glaze.

Wall tile when dust pressed are made in square or rectangular shapes. Glazed wall tile are made in the following sizes, 6 by 6 inches, 6 by 3 inches, 6 by 2 inches, $4\frac{1}{4}$ by $4\frac{1}{4}$ inches, $4\frac{1}{4}$ by $2\frac{1}{8}$ inches, also in special sizes 9 by 3 inches, and 9 by $4\frac{1}{2}$ inches. Though the design or single panel may be large, it is customary to make it up of a number of smaller pieces, as large ones would have a tendency to warp in the fire.

The use of wall tile has been well set forth by Charles F. Binns, who writes that "It is not necessary to point out the advantage of glazed tile in bathrooms, light shafts and underground offices. These are things of the past and are sufficiently obvious. A new day is dawning, however, in the use of ceramic decorations and in its advance there will be revealed possibilities at present imperceived."

They can be artistically used in places where wood and plaster were formerly exclusively employed. "Not only may a wainscot or frieze be filled with richly-toned tile glazed in a delicate texture matt, but panels, arches, and ceilings may be similarly treated. Such a surface is not only structurally sound and artistic, but perfectly sanitary, for the whole room may be washed without damage."

Properties of Floor Tile. Under this heading are included tile of a variety of shapes and colors which are used for flooring.

On account of the conditions under which they are used they should possess sufficient hardness to resist abrasive action, sufficient transverse strength to resist knocks and sufficient density to prevent absorption of water and dirt. It would be preferable if all were non-absorbent, but they are not.

The following figures will give the range of absorption percentages determined on a number of New Jersey tiles:

ABSORPTION OF NEW JERSEY FLOOR TILE.

Color.	Per cent absorption.
Blue	0–3.59
White	0–.031
Red	1.30–3.11
Pink	.8–3.70
Red brown	3.8–4.7
Buff	1.7–3.3
Green	1.6–6.63
Black	0–5.39
Gray	0–.5

Method of Manufacture. Great care is necessary in the selection and mixing of the raw materials, and the manufacturer must adjust his mixtures for the face of the tile and the backing in case they are different. Clay used for floor tile should be as free from soluble salts as those employed for the manufacture of pressed brick or terra cotta, although the soluble salts may come from the coloring materials used. Floor tile, when white, are commonly made of a mixture of white-burning clays, flint, and feldspar. Buff-colored tiles and artificially colored ones are usually made from fire clays, while red tiles are often made from red-burning clay or shale.

Floor tiles are nearly always molded by the dry-press process in hand-power machines. The tile are placed in saggers in the kiln for burning, and since there is in most cases no glaze only one firing is necessary.

Floor tile may be divided into plain and encaustic.

The plain tile are made of one clay throughout. Those recognized are the mosaics, which are $\frac{1}{4}$ inch thick and $\frac{1}{2}$ inch square and fastened to paper sheets. Other sizes are $\frac{3}{4}$ inch square, $\frac{3}{4}$ inch hexagon, 1 inch hexagon, $1\frac{3}{16}$ inch circle. The plain ones may be vitreous or semi-vitreous.

Large tile, known as quarry tile, 6 and 8 or more inches square, $\frac{3}{4}$ to 1 inch thick, and of red color, are much used now for flooring.

In recent years floor tile with a matt glaze have been occasionally employed, but their appropriateness for flooring is questionable, as the surface coating is likely to become cracked or chipped or worn off.

PLATE LVIII. — Encaustic tile. The design is superficial.

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Encaustic tiles have a facing of one kind of clay and a backing of another. Those which have a design of several colors are formed with the aid of a brass cell frame, of the same depth as the mold box used, and which consists of a framework of brass strips arranged so as to form the outline of the colors making the pattern. The framework is placed in the mold and the colored clays sifted into their proper divisions. This is done by using a sieve so perforated as to expose only certain cells, and filling the exposed cells with facing mixture of the desired color. This means, of course, that it is necessary to use as many sieves as there are colors in the design. When all the colors are filled in the cell frame is lifted out and the mold filled with the clay backing.

Encaustic tile have for their base buff and red-burning clay. Since the iron in these is mainly present as free oxide it is impossible to burn such tiles to vitrification without destroying the color.

Tests of Wall Tile. Here, again, we have no standard series of tests, but those applied to enameled brick may be regarded as about equally applicable to wall tile.

Tests of Floor Tile. The condition of use to which floor tile are subjected will no doubt suggest the tests which should be made upon them. The tests which the writer suggests are:

1. Determination of abrasive resistance in order to find out the rate and amount of ware under rubbing action.

2. Transverse test to determine the resistance of the tile to blows and the pressure of heavy weights.

3. Absorption. Tile of high absorptive power are undesirable as they soak up water and dirt.

4. Hardness. They should have a hardness of not less than 6 or 7.

5. Unfortunately, there are no accepted standards of comparison with which the first three sets can be checked up.

The following tests were made at the Watertown, Mass., Arsenal in 1894, on specimens supplied by the American Encaustic Tiling Co., Ltd. The tile were tested on edge.

Name and color.	Dimensions.			Sectional area, sq. in.	First crack, lbs.	Ultimate strength.		Per cent absorption by weight.
	Height, inches.	Compressed surface, inches.				Total lbs.	Per sq. in., lbs.	
1. Buff	3.00	3.00	.46	1.344	26,900	30,610	22,775	5 9
2. Salmon	2.98	2.98	.44	1.275	25,800	53,500	41,961	2.8
3. Light gray	2.98	2.98	.46	1.335	27,300	65,100	48,764	3.1
4. Dark gray	2.99	2.99	.46	1.389	26,800	47,700	35,263	2.1
5. Red	3.00	3.00	.49	1.434	23,200	35,650	24,860	3.2
6. Chocolate	2.98	2.98	.46	1.335	29,100	47,360	35,475	2.1
7. Black	2.98	2.98	.47	1.365	22,700	24,200	17.729	9.9
7. Black	2.97	2.98	.46	1.335	22,700	24,600	18,427	.....
8. White bisque	3.00	3.00	.48	1.404	3,100	26,880	19,145	.....
8. White vitrified	2.99	3.00	.48	1.404	15,400	65,800	46,866	.06
9. Silver gray vitrified	2.99	2.99	.49	1.429	3,400	48,100	33,660	0
10. Pink	2.99	2.99	.49	1.429	4,700	42,700	29,881	.06
11. Celadon	3.01	3.01	.50	1.469	2,400	72,900	49,625	.....
12. Light blue	2.99	2.99	.50	1.459	20,400	25,700	17,615	.12
13. Dark blue	2.99	2.99	.49	1.429	45,500	45,750	32,015	23
14. Green	2.99	2.99	.47	1.369	3,200	27,800	20,307	.12
15. Alhambra	6.00	6.00	.58	3.480	97,300	173,200	49,770	.04
16. Alhambra	5.98	5.99	.57	3.414	43,000	167,800	49,150	.05
17. Alhambra	5.99	6.00	.58	3.480	54,800	213,200	61,264	.06
18. Glazed white	2.98	5.96	.33	1.967	10,100	17,500	8,897	14 2
19. Glazed ivory	3.00	5.99	.33	1.977	7,800	24,860	12,575	12.3

A series of tests made to determine the wearing qualities of flooring materials was published in the *Scientific American* for July 3, 1897. They are of interest as showing the comparative wearing qualities of floor tile and other materials used for the same purpose. The following statements are quoted from this article. The materials tested were rubber tile, English earthenware tile, Vermont marble, marble mosaic, flagstone, Oregon pine, teak wood, white pine and oak. The experiments were carried out by Messrs. William Gray & Sons, and were made under the careful supervision of Mr. William J. Gray.

In carrying out the tests the specimens were cemented to identical blocks of sandstone, each of which weighed twenty-one pounds. The samples represented a surface six inches square, and the thickness of each sample was the same as that commonly used in the various floorings. The interlocking rubber tile specimen was $\frac{3}{8}$ inch thick, the No. 1 Vermont marble was 1 inch thick, the Oregon pine $2\frac{3}{4}$ inches thick, and so on.

The samples were all placed face downward upon a horizontal iron rubbing wheel 10 feet in diameter, which was run for a period of one hour at a speed of 75 revolutions per minute. A suitable frame held the blocks loosely in place and prevented

them from rotating with the wheel, care being taken to let the full weight of the blocks bear upon the wheel. The face of the wheel was freely supplied during the test with the best sharp rubbing sand and water.

The results were full of surprises. By far the best showing was that made by the interlocking rubber tile, which only lost $\frac{1}{64}$ inch as the result of an hour's grinding. On the other hand, the marble mosaic collapsed altogether, the one-inch strip being rubbed entirely away within fifteen minutes under a pressure of a little over half a pound to the square inch. The whole slab disappeared in thirty-five minutes under the same pressure.

Next to the rubber, the English earthen tile showed by far the best results, losing only $\frac{1}{3}$ inch in thickness; and of the stones, the granolithic made the best showing, losing $\frac{3}{8}$ inch, flagstone coming next with $\frac{9}{16}$ inch wear. The marbles wore away very fast, No. 1 Vermont marble losing $\frac{3}{4}$ of an inch. Their average resistance, indeed, was not as high as that of the woods.

One of the most curious results is shown in the action of the woods, where teak lost nearly double as much as the softer white pine, the wear being respectively $\frac{3}{16}$ and $\frac{7}{16}$ of an inch. Yellow pine showed the same wear as white pine, and the oak specimen lost the same amount as its great rival Oregon pine, which was reduced by $\frac{5}{8}$ inch.

CHAPTER XIV.

SEWER PIPE.

Raw Materials. This class of ware, which is sometimes called sanitary pipe, is made from a clay or shale, or mixture of two or more kinds of these materials, whose physical properties are such that they will either burn to a vitrified body or one of low absorption and also take a salt glaze. In some sewer-pipe mixtures a fire clay is used as one of the ingredients, in others only non-refractory clays are employed.

Manufacture. Sewer-pipe clays are thoroughly ground if necessary, well mixed and then molded in a special form of press, from which the clay issues through a die of the proper form. Special shapes, such as traps, sockets and elbows, are usually made by hand in plaster molds and require careful drying. At times Y shapes are made by cutting one straight piece on the slant and joining it onto a pipe with wet clay. T's are made in a similar manner.

Sewer-pipe are slowly dried on slatted floors, heated by steam pipes, and burned in down-draft kilns. When the kiln has reached a temperature of not less than 1150° C., salt is thrown into the fires and the sodium vapors passing through the kiln, unite with the clay, forming a glaze on the surface of the ware known as a "salt glaze." Many clays are capable of taking a good salt glaze, but some take a poor one, and others do not glaze at all. A poor salt glaze might be due to the character of the raw material, too low temperature of burning, or the latter combined with presence of an excess of soluble salts.

A sewer pipe is sometimes glazed with an easily fusible clay, known as a "slip clay." This is applied to the surface of the pipe previous to burning and melts to a glassy coat at the temperature of firing. This practice has been abandoned in the

United States, as the salt glaze is cheaper and equally satisfactory. Sewer pipes are made in diameters from 3 up to 36 inches.

The following table of data, taken from the catalogue of one large manufacturer, may be of interest:

Inside diameter, inches	3	4	5	6	8	9	10	12	15	20	21	22	24
Weight per foot in pounds	7.5	10	11	16.5	24	28	32	39	58	77	105	125	140
Area in inches	7	12	19	28	50	64	78	113	177	254	345	390	455
No. of feet in average car load	3400	2600	2000	1599	1000	900	750	600	400	300	240	190	180
Thickness in inches	$\frac{5}{16}$	$\frac{5}{8}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{8}$	$\frac{7}{8}$	$\frac{7}{8}$	1	$1\frac{1}{8}$	$1\frac{1}{4}$	$1\frac{3}{4}$	$1\frac{3}{4}$	$1\frac{3}{4}$

The following data of a somewhat different character are taken from the catalogue of another company:

APPROXIMATE WEIGHTS, DIMENSIONS, ETC., STANDARD SEWER PIPE.

Calibre, inches.	Thickness, inches.	Weight per foot, pounds.	Depth of sockets, inches.	Annular space, inches.
2	$\frac{7}{16}$	5	$1\frac{1}{2}$	$\frac{1}{4}$
3	$\frac{1}{2}$	7	$1\frac{1}{2}$	$\frac{1}{4}$
4	$\frac{1}{2}$	9	$1\frac{5}{8}$	$\frac{3}{8}$
5	$\frac{5}{8}$	12	$1\frac{3}{4}$	$\frac{3}{8}$
6	$\frac{5}{8}$	15	$1\frac{7}{8}$	$\frac{3}{8}$
8	$\frac{3}{4}$	23	2	$\frac{3}{8}$
9	$\frac{13}{16}$	28	2	$\frac{3}{8}$
10	$\frac{7}{8}$	35	$2\frac{1}{8}$	$\frac{3}{8}$
12	1	43	$2\frac{1}{4}$	$\frac{1}{2}$
15	$1\frac{1}{8}$	60	$2\frac{1}{2}$	$\frac{1}{2}$
18	$1\frac{1}{4}$	85	$2\frac{3}{4}$	$\frac{1}{2}$
20	$1\frac{3}{8}$	100	3	$\frac{1}{2}$
21	$1\frac{1}{2}$	120	3	$\frac{1}{2}$
22	$1\frac{5}{8}$	130	3	$\frac{1}{2}$
24	$1\frac{5}{8}$	140	$3\frac{1}{4}$	$\frac{1}{2}$
27	2	224	4	$\frac{3}{4}$
30	$2\frac{1}{8}$	252	4	$\frac{3}{4}$
33	$2\frac{1}{4}$	310	5	$1\frac{1}{4}$
36	$2\frac{1}{2}$	350	5	$1\frac{1}{4}$

DOUBLE STRENGTH PIPE.

15	1¼	75	2½	½
18	1½	118	2¾	½
20	1⅔	138	3	½
21	1¾	148	3	½
22	1⅞	157	3	½
24	2	190	3¼	½
27	2¼	265	4	¾
30	2½	290	4	¾
33	2⅝	335	5	1¼
36	2¾	375	5	1¼

Requisite Qualities. Sewer pipe should be free from pimples, blisters and cracks; the glaze should be continuous and as smooth as possible; the pipe should be straight and free from cracks. A dark color is preferred by most engineers and architects.

The cause of the defects are the following:

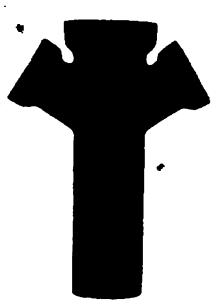
Blisters may be due to air imprisoned in the clay during molding. Surface pimpling, found more or less on salt glazed pipe, appears to be related to the texture of the body and treatment during firing. To state it in more detail: The pimples are caused by incipient fusion, bubbling and swelling of small particles of shale, or perhaps concretionary matter (such as pyrite and limonite) lying close to the surface. They can be prevented usually by finer grinding of the raw material. Rapid burning seems to encourage their development. Poor glaze may be due to the clay, too low heat in firing or not enough salt.

Warping and cracking may be due to uneven mixing, uneven heating or inability of pipes to stand weight of those set on top of them in the kiln. Fine cracks may develop in the drying and open still further in the burning.

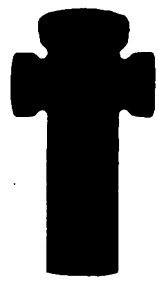
In preparing a set of specifications for sewer-pipe tests, the committee of the American Society for Testing Materials has pointed out the existence of the following demands.[1]

(a) *Strength.* This includes resistance against rupture, homogeneity of the material and the vitrification of clay pipe.

[1] Vol. IX, p. 263.



Double Y



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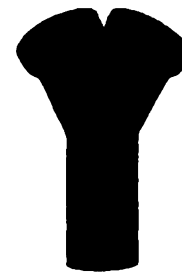

Y Branch

Increaser

1 Foot Slant

Single H. H. Trap

Double H. H. Trap

Channel Pipe

S Trap

Socket Pipe

Rubber Trap

P Trap

PLATE LIX. — Sewer pipe and fittings.

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ASTOR, LENOX AND
TILDEN FOUNDATIONS

It includes also the necessary data for the thickness of shell and the importance of fire cracks in vitrified pipes.

The proper requirements should be stated for the strength necessary to resist crushing, bursting and impact under various practical conditions.

(b) *Durability.* This includes resistance to wear and tear. There should be given the required resistance against abrasion by sand or gravel at high velocities in glazed and unglazed pipes, the density or specific gravity of the material with relation to its porosity and capillary absorption of moisture.

There should be considered the corrosion of glazed and unglazed vitrified clay pipes by acids, alkalies, steam, frost and gases.

(c) *Serviceability.* This relates to the efficiency of the pipes to perform the best service.

Under this heading should be considered the question of smoothness, the glazing of vitrified pipes, blisters, the best sectional form for various purposes, and the warping of pipes, including the permissible deviation from true, straight pipes and regular curves or specials.

The best lengths of the individual straight pipes and specials should be determined.

The ends of pipes with reference to making the best joints should receive most careful study to determine the best practice for different conditions, including hub and spigot, butt and collar, and beveled joints.

All specials, such as branches, spurs, curves, etc., should receive attention with reference to recommendations as to size and form.

Specifications. The following specifications for sewer pipe are given by Johnson in his work on Engineering Contracts and Specifications.

Straight sections are termed " pipes "; branches, bends, reducers, etc., are fittings, " specials " or special pieces.

All hubs or sockets should be of sufficient diameter to receive spigot end of next following pipe or special to full depth, without chipping, and leave $\frac{1}{8}$ inch all around for mortar.

In the case of pipes and specials 12 inches and upward in diameter at least 40 per cent shall be truly or substantially circular. If less than 12 inches in diameter, at least 60 per cent circular. Of those that are not circular all that show long diameter more than from 6 to 7 per cent greater than short one are to be rejected. Pipes and specials showing angles, sharp curves or flat curves to be rejected.

A single fire crack extending through whole thickness of pipe must not be more than two inches long at spigot end or more than one inch long at hub end, measured from shoulder in the latter case. Two or more such cracks at either end cause rejection.

A single fire crack extending through two-thirds of the thickness of pipe must not be over four inches long. Two or more such cracks cause rejection.

A single fire crack extending through one-half of the thickness must not be over 6 inches long. Two or more cause rejection of the pipe.

A single fire crack extending through less than one-half of the thickness of the pipe must not be over 8 inches long. Two or more cause rejection.

A transverse fire crack must not be longer than one-sixth of the circumference or more than one-third of the thickness in depth. Two or more cause rejection.

No fire cracks shall be over one-eighth of an inch wide at widest point.

No combinations of above limitations allowed except by special consent.

Any pipe or special cracked through whole thickness from any other cause than burning rejected. This refers to transportation, cooling, frost, etc.

Irregular lumps or unbroken blisters on interior surface sufficient to appreciably retard flow cause rejection.

Broken blisters or flakes must not exceed in thickness one-sixth of the thickness of the pipe or in greatest diameter one-twelfth of the circumference of the pipe.

Any broken blister or flake so placed that proper fitting of pipe cannot bring it on top will cause rejection.

The same applies to broken blisters on outside.

Any pipe showing in any manner a want of thorough vitrification or fusion or use of improper materials or methods shall cause rejection.

All pipe supposed to be straight shall not show any material deviation.

No piece broken out of rim of either hub or socket of pipe shall be greater than one-tenth of the circumference of the pipe. And any break, even within limits, shall cause rejection if pipe cannot be fitted so as to bring break at top.

A. Marston [1] points out that the standard tests of drain tile and sewer pipe should develop two cardinal qualities: (*a*) The bearing strength of the pipe under approximate conditions and for which he proposes a direct bearing-strength test. (*b*) The quality of the material in the shell of the pipe to resist disintegration, which he proposes to determine by:

1. The modulus of rupture of the material, calculated from the data of the bearing-strength test, to show the strength of the material.

2. An absorption test of the material to show its resistance and the penetration and action of destructive agencies.

The need of standard tests is shown by the fact that in many cases large pipe are found to be cracked when inspected in building sewers and drains, and that this cracking is sometimes caused by comparatively shallow depths of ditch filling.

As a result of numerous experiments in Iowa, the Iowa Engineering Experiment Station has devised the following specifications for standard tests:

Iowa Standard Specifications for Drain Tile and Sewer Pipe. Absorption Tests. 1. *Specimens.* The specimens shall be each approximately three inches square, and shall extend the full thickness of the pipe wall, with the outer skins unbroken.

2. *Number of Test Specimens.* Five individual tests shall constitute a standard test, the average of the five and the result for each specimen being given in the report of the test.

[1] Proceedings American Society for Testing Materials, Vol. XI, p. 833; see also "Municipal Engineering," Vol. 30, p. 288, and Vol. 34, p. 294.

3. *Drying Specimens.* Each specimen shall be dried in an oven, or by other application of artificial heat, until it ceases to lose further appreciable amounts of moisture when repeatedly weighed.

4. *Brushing Specimens.* All surfaces of the specimens shall be brushed with a stiff brush before weighing the first time.

5. *Weighing.* The specimens shall be weighed immediately before immersion, on a balance or scales capable of accurately indicating the weight to within one-tenth of one per cent.

6. *Water for Standard Test.* The water employed in the standard absorption test shall be pure soft water, at the air temperature of a room which is artificially heated in cold seasons of the year.

7. *Immersion of Specimens.* The specimens shall be completely immersed in water for a period of 24 hours.

8. *Re-weighing.* Immediately upon being removed from the water, the specimens shall be dried by pressing against them a soft cloth or a piece of blotting paper. There shall be no rubbing or brushing of the specimen. The re-weighing shall be done with a balance or scales capable of accurately indicating the weight to within one-tenth of one per cent.

9. *Calculation of Result.* The result of each absorption test shall be calculated by taking the difference between the initial dry weight and final weight, and dividing the remainder by the initial dry weight.

Bearing Strength. 1. *Specimens.* The specimens shall be unbroken, full-sized samples of the pipe to be tested. They shall be carefully selected so as to represent fairly the quality of the pipe.

2. *Number of Specimens.* Five individual tests shall constitute a standard test, the average of the five and the result for each specimen being given in the report of the test.

3. *Drying.* The specimens shall be dried by keeping them in a warm, dry room for a period of at least 2 days prior to the test.

4. *Weighing.* Each dried specimen shall be weighed on reliable scales just prior to the test.

5. *Bedding of Specimen for Test.* Each specimen shall be accurately marked, with pencil or crayon lines, in quarters, prior to the test. Specimens shall be carefully bedded above and below in sand for the one-fourth circumference of the pipe, measured on the middle line of the tile wall. The depth of bedding above and below the tile at the thinnest point shall be

equal to one-fourth the diameter of the pipe, measured between the middle lines of the tile walls.

6. *Top Bearing.* The top-bearing frame shall not be allowed to come in contact with the tile or the test load. The upper surface of the sand in the top bearing shall be carefully struck level with a straight edge, and shall be carefully covered with a heavy rigid top bearing, with lower surface a true plane made of heavy timber or other rigid material capable of uniformly distributing the test load without any appreciable bending. The test load shall be applied at the exact center of this top bearing in such a way, either by the use of a spherical bearing or by the use of two rollers at right angles, as to leave the bearing free to move in both directions. In case the test is made without the use of a machine and by piling on weight, the weight may be piled directly on a platform resting on the top bearing, provided, however, that the weight does not touch the top frame holding the sand, and provided, further, that the weight is piled in such a way as to insure uniform distribution of the load over the top surface of the sand.

7. *Frames for Top and Bottom Bearings.* — The frames for the top and bottom bearings shall be composed of timbers so heavy as to avoid any appreciable bending by the side pressure of the sand. The frames shall be dressed on their interior surfaces. No frame shall come in contact with the tile during the test. A strip of soft cloth may be attached to the inside of the upper frame on each side along the lower edge, to prevent the escape of sand between the frame and tile.

8. *Sand in Bearings.* The sand used for bedding the tile at the top and bottom shall be washed sand which has passed a No. 8 screen. It shall be dried by keeping it spread out thin in a warm, dry room.

9. *Application of Load.* The test load shall be applied gradually and without shock or disturbance of the tile. The application of the load shall be carried on continuously, and the tile shall not be allowed to stand any considerable length of time under a load smaller than the breaking load.

10. *Calculation of the Bearing Load.* The total breaking load shall be taken as equal to the total top load, including the weight of top frame, sand for top bearing, top bearing timbers, etc., plus five-eighths the weight of the pipe. This total load shall be divided by the length of the pipe in feet so as to give the bearing strength per linear foot of pipe.

Computing the Modulus of Rupture. The modulus of rupture

for drain tile and sewer pipe shall be computed from the results of the standard test for bearing strength, according to the following rule:

Divide the bearing strength per linear foot by twelve, multiply the quotient by the radius of the middle line of tile wall expressed in inches, and divide this product by the square of the minimum thickness of the tile wall at top or bottom, also expressed in inches. This quotient will be the modulus of rupture of the pipe, expressed in pounds per square inch.

The formulas on which the above specifications are based are derived in the usual manner for flexible rings subjected to uniform vertical loads, over 90° of the circumference above and the same distance below. The mathematical details of the derivation will not be given. Use is made in work of both the static and the elastic equations of equilibriums.

BRIEF SUMMARY OF ABSORPTION TESTS OF DRAIN TILE AND SEWER PIPE. IOWA STANDARD METHOD.

Tests of Clay Drain Tile.

No. of tests.	No. of kinds.	Diameter of tile, ins.	Per cent of absorption.		
			Minimum.	Maximum.	Average.
4	1	5	15.0	18.5	16.3
30	3	6	2.6–4.0	7.3–8.3	4.8–6.1
2	2	8	.....	.....	3.6–19.0
42	2	12	2.4–3.9	7.6	5.0–5.8
5	1	18	4.1	8.8	5.5
4	1	28	4.8	6.1	5.4
5	1	30	3.4	5.2	4.3

Other Proposed Standard Tests. A number of other methods of making bearing-strength tests of drain tile and sewer pipe have been advocated or used. Together with the above method, they may be enumerated as follows:

1. Completely surrounding the pipe with sand in a very strong box. The author understands that this method was in use for a time in Brooklyn. It has been strongly advocated by Blackmer and Post of St. Louis, in recent correspondence, and they have made a new design for the enclosing box and the bearings.

2. Bedding the pipe on sand at the bottom, while applying the top load to a narrow bearing strip. The author would designate this the Brooklyn Method, as it is in regular use by the sewerage engineers of that city.

BRIEF SUMMARY OF BEARING-STRENGTH TESTS. IOWA STANDARD METHOD.

Tests of Clay Tile.

No. of tests.	No. of kinds.	Diameter of tile, ins.	Bearing strength, lbs. per lin. ft.			Modulus of rupture, lbs. per sq. in.		
			Minimum.	Maximum.	Average.	Minimum.	Maximum.	Average.
7	2	5	640–1340	680–1700	650–1530	400–870	430–1110	410–1000
39	5	6	590–2200	1090–2910	780–2530	420–1400	820–2360	570–1830
3	1	7	810	1230	960	630	1080	800
17	5	8	760–1300	1060–2220	890–2220	570–1900	780–1900	670–1900
6	1	10	1690	2150	1980	1060	1440	1320
53	4	12	870–2080	1770–4140	1470–2800	450–1390	1050–3020	790–1940
5	1	18	1540	2010	1740	650	1000	830
5	1	24	1880	2400	1990	840	1420	1090
4	1	28	1860	4170	3340	580	1360	1090
5	1	30	2740	4630	3420	1000	1410	1300

Tests of Clay Sewer Pipe.

3	1	6	1430	2010	1770	930	1460	1150
8	2	8	1570–1950	2060–3320	1820–2690	1020–1240	1170–2320	1100–1730
4	1	10	1890	2840	2320	1100	1660	1350
3	1	12	1690	2500	2150	930	1350	1180
2	1	15	1630	2000	1820	980	1200	1090
4	1	24	2170	5110	3520	1280	2760	2080

3. The Iowa Standard Method, already described herein, beds the pipe in sand for 90° at the top, and the same amount at the bottom.

4. In the so-called Three Point Method, the pressure is applied along a single narrow bearing strip at the top, while the pipe is supported at the bottom on two similar bearing strips, placed parallel, a few inches apart. This method has been developed by Mr. C. W. Boynton, of Chicago, and in the laboratory of Professor A. N. Talbot, of the University of Illinois. The Iowa Engineering Experiment Station has made quite a number of comparative tests with this method.

5. In the method of Concentrated Loadings, the top load would be applied to a narrow bearing strip, as in Methods 2 and 4, and the bottom of the pipe would be supported on a similar bearing strip.

Miscellaneous Tests. The following tests of sewer pipe are given in Ogden's book on Sewer Construction. Tests were made by J. H. Shedd, 1879, on pipes half bedded in sand. Results show crushing strength in pounds per linear foot.

	No. of kinds.	Minimum.	Maximum.	Average.
12-inch pipes	4	1456	1765	1601
15-inch pipes	4	1261	1765	1452
18-inch pipes	3	1464	1942	1670

A set of hydrostatic tests were made in 1890 by M. A. Howe, by having the end of the pipe closed and the water pumped in until the pipe broke. The average tensile strength of the material for the different sizes was as follows:

4-inch	517 pounds
6-inch	678 pounds
8-inch	552 pounds
10-inch	702 pounds
12-inch	592 pounds
18-inch	529 pounds
21-inch	617 pounds
24-inch	856 pounds

A drop test showed that the sewer pipe has strength enough to sustain ordinary blows, but that, where successive blows are to be expected, sufficient covering is to be provided.

In a concentrated-load test, an average pipe stood 2000 pounds at the center, with supports 16 inches apart.

The uniform-load test showed that the larger sizes stood a little over 2000 pounds per linear foot of pipe, and the smaller sizes up to 8000 pounds.

Mr. Barbour, city engineer at Brockton, Mass., recommended, as a result of tests made by him, that pipe be required to have a breaking load of 3000 pounds per linear foot for a standard, and 4500 pounds per linear foot for double-strength pipe, the thickness to vary with the diameter to give this strength.

Other tests made in 1894 by the city engineer of Providence, R. I., showed the following variation in the crushing strength per linear foot:

8-inch: Minimum, 757 pounds; Maximum, 2498 pounds
12-inch: Minimum, 924 pounds; Maximum, 2816 pounds
15-inch: Minimum, 1063 pounds; Maximum, 2666 pounds
18-inch: Minimum, 1305 pounds; Maximum, 2401 pounds

These were simply to indicate the danger of pipes breaking even if loaded approximately to what the average pipe will bear.

Other Hollow Shapes. Among the other hollow shapes often made at sewer-pipe works are fire-clay stove-pipe fittings, such as thimbles, flue tops, and flue linings. The latter are made either with circular section or rectangular with round corners, and usually in two-foot lengths.

The weights of flue linings in two-foot lengths are about as follows:

4½ × 8½ inches outside	14 pounds
6 × 12 inches outside	22 pounds
8½ × 8½ inches outside	18 pounds
8½ × 13 inches outside	28 pounds
12 × 16 inches outside	45 pounds
13 × 13 inches outside	38 pounds
13 × 18 inches outside	57 pounds
14 × 16 inches outside	50 pounds
18 × 18 inches outside	75 pounds

Vitrified round drain tile are now produced in large quantities at some sewer-pipe works. They are either glazed or unglazed. The following figures are given by one factory:

Diameter, inches.	Weight per foot, pounds.	No. of feet drain tile in carload (3000 pounds).
2	3½	....
2½	4	7500
3	5	6000
4	7½	4000
5	10	3000
6	13	2310
8	20	1500
10	30	1000
12	40	750

Sewer Blocks. These are hollow, segmental blocks, which are used in the construction of large diameter sewers, ranging, say, from 36 inches to 108 inches. Like the sewer pipe they are or should be vitrified, and are also salt glazed.

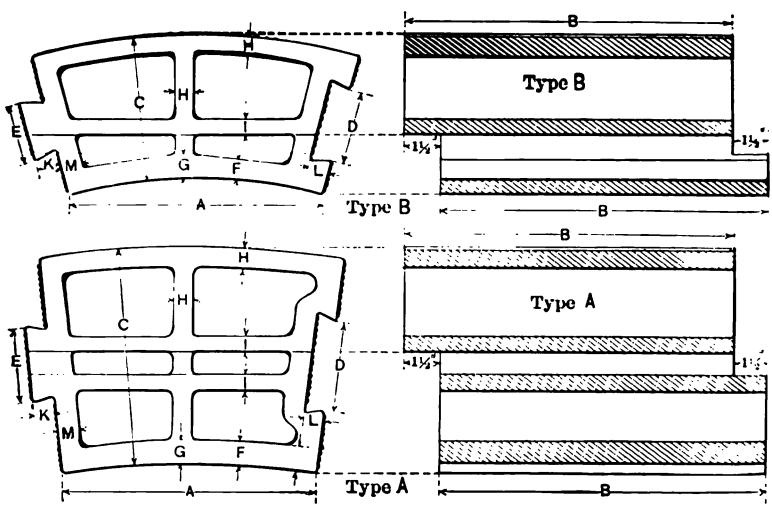

Fig. 20. — Sections of sewer blocks. (American Sewer Pipe Company.)

The following data are taken from the catalogue of the American Sewer Pipe Company.

Diameter.	Number of block.	Length.	Thickness.	Cross section dimensions.											Weight.	
				A.	B.	C.	D.	E.	F.	G.	H.	I.	K.	L.	M.	Block, per foot.	Foot of sewer.
ins.		ins.	ins.	ins.	ins.	ins.	ins.	ins.	ins.	ins.	in.	in.	in.	in.	in.	lbs.	lbs.
36	10	24	6	11	24	6	3	2⅝	1⅜	1/8	1⅛	1⅜	1/8	1/8	1⅜	37½	375
42	12	24	6	10¾	24	6	3	2⅝	1/8	1/8	1/8	1/8	1/8	1/8	1/8	37½	450
48	14	24	6	10½	24	6	3	2⅝	1/8	1/8	1/8	1/8	1/8	1/8	1/8	35	490
54	16	24	6½	11 5/16	24	6½	3 1/16	2¾	1/8	1/8	1/8	1/8	1/8	1/8	1/8	35½	568
60	16	24	7¼	11½	24	7¼	3⅜	3	1/8	1	1/8	1/8	1/8	1/8	1/8	43¾	700
66	18	24	8	11¼	24	8	3⅜	3 1/16	1/8	1/8	1/8	1	1/8	1/8	1/8	50½	909
72	20	24	8½	11 1/16	24	8½	3½	3⅛	1/8	1/8	1/8	1/8	1/8	1/8	1/8	50	1000
78	22	24	8⅞	10⅞	24	8⅞	3⅝	3 1/16	1/8	1/8	1/8	1/8	1/8	1/8	1/8	50	1100
84	24	24	9	10¾	24	9	3⅝	3 1/16	1/8	1/8	1/8	1/8	1/8	1/8	1/8	51	1224
90	26	24	10	10⅝	24	10	3⅝	3⅜	1/8	1/8	1/8	1/8	1/8	1/8	1/8	53½	1391
96	28	21	11	10¾	21	11	3⅞	3⅝	1/8	1	1/8	1/8	1/8	1/8	1/8	58	1624
108	32	18	12	10⅜	18	12	4¼	3⅞	1	1 1/16	1/8	1/8	1/8	1/8	1	67	2144

SANITARY WARE.

Sanitary ware is divided into two classes, viz.:

(1) *Vitreous Ware*, from which are made water-closets, tanks, high and low lavatories and drinking fountains. This class of ware is made in two fires, viz., biscuit and glost fire.

(2) *Solid Porcelain*, so called in the trade, the body being made of fire clay and fire-clay grog, which is covered with a white vitreous lining, the latter in turn being covered with a hard, clear, feldspathic glaze. The lining and glaze are applied to the green ware, and the whole burned in one fire in a rectangular muffle kiln. In this type are made solid porcelain bath-tubs, urinals, stalls, laundry trays, kitchen and pantry sinks, slop sinks, lavatories, etc. It is sold as A, B, C grades.

When the white lining is omitted a buff-colored ware results, which is of a cheaper grade and known as *Continental ware*.

Raw Materials. The body of vitreous ware consists of several grades of kaolin, ball clay, whiting, flint and feldspar. The body of solid porcelain ware is made of a mixture of several grades of fire clay and fire-clay grog. The glaze of the former consists of feldspar, cornwall stone,[1] whiting, zinc oxide, white lead, kaolin, flint and boric acid, while the glaze of the solid porcelain ware is similar but contains no lead and tin oxide.

Manufacture. Sanitary ware is formed by hand in plaster molds. Great care has to be taken to mix the clays properly and to dry the ware slowly after it has been formed. Vitreous ware is first burned to the " biscuit " condition, then glazed and fired again in the glost kiln, but at a lower temperature, in order to fuse the glaze.

The solid porcelain has the glaze applied to the green ware and the whole fired in one operation.

Properties of Sanitary Ware. The body of both kinds of sanitary ware should be steel hard, and the vitreous ware is non-absorbent. They should not discolor, and the glaze should be smooth and free from cracks.

The visible defects are chiefly in the glaze, which may dunt, fire crack, or craze. It may also shrink away from the edges of

[1] A partially decayed granite.

the ware. The glaze may also show green or brown spots. If underfired it is dull, if overfired it blisters.

Proper shrinkage of the ware in burning is highly important.

The disadvantages claimed for marble, slate and soapstone, as compared with clay ware, are that they lack uniformity of color, are not non-absorbent, and in the case of marble at least are affected by acid waters. Glass is claimed to be more brittle than the clay ware. Enameled iron ware is said by some to be less durable.

Sanitary ware made of burned clay is now widely used in the United States. It has grown tremendously in favor in recent years and has also improved greatly in quality. Much was formerly imported from Europe.

An objection urged by some is the higher cost and great weight. A finished bathtub may commonly weigh from 500 to 800 pounds, according to size and shape.

GLOSSARY.

Adobe. A sandy, often calcareous clay, much used in warm climates for making sunbaked (adobe) brick.

Air shrinkage. The decrease in volume which a clay undergoes in drying.

Air brick. A hollow or pierced brick built into a wall to allow the passage of the air.

Alabaster. A white, massive variety of gypsum.

Amphibole. A group name including a number of mineral species, which are essentially silicates of alumina, magnesia, lime and iron. They are found in both igneous and metamorphic rocks. Hornblende is the commonest species.

Anticline. An arch-like fold.

Apatite. A mineral occurring in many granites, but usually in small quantities. It is a phosphate of lime and has a hardness of 5.

Aplite. A fine-grained granite, consisting normally of quartz and feldspar, and usually occurring in dikes.

Aragonite. A mineral having the same composition as calcite (calcium carbonate) but differing from it in crystalline form.

Arch brick. Commonly applied to those brick taken from the arches of a kiln. They are usually overburned.

Argillaceous. A common term applied to rocks containing clayey matter.

Arkose. A variety of sandstone containing much feldspar.

Ashlar brick. A term often applied to certain brick whose one edge is rough chiseled to resemble rock-faced stone.

Ball clay. A plastic white-burning clay used as a bond in china ware.

Basalt. An igneous rock of volcanic character, composed chiefly of pyroxene and plagioclase feldspar. It is usually fine-grained and black, is common in the northwestern states, but is little used for building purposes. See *Trap.*

Bastard granite. Many quarrymen apply this term to gneissic granites.

Bate. See *False cleavage.*

Bedding. See *Stratification.*

Biotite. A mica, essentially a silicate of aluminum, magnesia and iron, of black or dark green color.

Black coring. The development of black or bluish black cores in bricks, due to improper burning.

Blind seams. Incipient joints.

Bluestone. An indefinite term commonly applied to sandstones of a bluish gray color. In Maryland it is used for a gray gneiss, and in the District of Columbia for a mica schist. The well-known bluestone of eastern New York is used for flagging.

Book tiles. Flat, hollow shapes, having two segmental edges and resembling a book in section.

Boulder quarry. A quarry in which the joints are numerous and irregular, so that the stone is naturally broken up into comparatively small blocks.

Breccia. A rock composed of angular fragments, usually cemented together.

Brick clay. Any clay that can be used for brick manufacture.

Brownstone. A term properly referring to a brown sandstone, but now very loosely used.

Calcareous. Containing lime, as a calcareous sandstone or calcareous clay.

Calcareous tufa. A porous mass of lime carbonate, deposited around the mouth of springs, as in swamps, or on rock ledges. It often forms a coating on plants.

Calcite. A mineral species composed of lime carbonate. The chief constituent of many limestones.

Calc-sinter. Same as *Calcareous tufa.*

Calico marble. A name applied to the limestone conglomerate quarried near Point of Rocks, Maryland.

Cellular. Containing cells, vesicles or cavities. A term most often applied to lavas.

Chalk. A soft limestone, of earthy texture and usually white color. Not of much use as a building stone.

Chert. A non-crystalline variety of quartz, often occurring as concretions in limestones. It is either dark or light in color and has a conchoidal or rounded fracture.

China clay. See *Kaolin.*

Chlorite. A group name for certain micaceous minerals, usually of greenish color, and being silicates containing alumina, iron and magnesia. Common in metamorphic rocks. Hardness, 2–2.7.

Cipolino marble. A white marble, having veins of greenish mica.

Clay. An earthy rock, having plasticity when wet, and hardening when burned.

Clay holes. Cavities in stones often filled with sandy or clayey matter, which usually falls out on exposure to the weather.

Cleavage. The property which some minerals and metamorphic rocks have of splitting readily in certain definite directions, which, in the case of minerals, are at a constant angle with themselves and with respect to the crystal form.

Clinker brick. A very hard-burned brick.

Conchoidal fracture. This applies to a curved break, resembling the curve of a clamshell. Dense rocks and some minerals often break in this way.

Concretionary. Made up of concretions.

Concretions. More or less rounded bodies of foreign matter found in some sedimentary rocks. They are often chert in limestone, and lime carbonate or iron carbonate in some clays and shales.

Conglomerate. A sedimentary rock made up chiefly of rounded fragments. Also called *pudding stone.*

Continuous kiln. One in which the waste heat from the cooling or hot chambers of brick is used to heat up the wares in other compartments still to be burned.

Coquina. A limestone made up of loosely cemented shell fragments.

Coral limestone. One composed of coral fragments. Such a rock is much used in the Bermuda Islands.

Cresting. Trimming used on the ridge of tiled roofs. Same as *Hip rolls.*

Crocus. A name applied to gneiss or other rock in contact with granite, in some quarries.

Cryptocrystalline. Finely crystalline. A term applied to igneous rocks.

Crystalline rocks. A term applied to those rocks composed of interlocking crystalline mineral grains, which have crystallized from fusion or solution.

Cut-off. The direction along which granite must be channeled because it will not split.

Deck molding. Trimming made to match cresting or ridging, on clay-tiled roofs, and used for the purpose of covering the planes of a roof which has a flat deck.

Decomposition. A term sometimes used to refer to the chemical breaking down of a rock on weathering.

Diabase. An igneous rock of ophitic (q. v.) texture, usually fine to medium grained, and consisting chiefly of pyroxene and plagioclase feldspar.

Dike. Igneous rock which has been forced into a fissure which is narrow as compared with its other dimensions. It may vary from a few inches to a number of feet in width.

Dimension stone. Stone that is quarried or cut of required dimensions.

Diorite. An igneous rock, usually of granitic texture, either fine or coarse grained, and composed essentially of plagioclase, feldspar and hornblende.

Diorite porphyry. A rock of porphyritic texture, but of the same mineral composition as diorite.

Dip. The slope of strata, or the angle which they make with a horizontal plane.

Disintegration. A term often applied to the natural mechanical breaking down of a rock on weathering.

Dolomite. A mineral which is a double carbonate of calcium (lime) and magnesium. Also a rock consisting chiefly of the mineral dolomite.

Down-draft kiln. One in which the heat enters the kiln chamber from the top and passes down through the ware.

Dries or *Dry.* A seam in the rock, which is usually invisible in the freshly quarried material, but which may open up in cutting or on exposure to the weather.

Dryer white. A white scum which forms on brick during drying.

Dry pan. A circular revolving pan with perforated bottom, in which two large rollers revolve by friction against the pan floor. It is used for grinding dry clays.

Dry-press process. A method of forming clay wares by using slightly moistened clay in pulverized form and pressing it into steel dies.

Dust pressed. Same as dry pressed. Usually applied to manufacture of wall tile.

Eave tile or *Starters.* These are roofing tile, closed underneath at the lower end. They are placed at the eave line.

Enameled brick. Brick which are coated on one or two surfaces with a white or colored enamel.

Encaustic tile. Floor tile having a surface pattern of one type of clay and backing of a different one.

End bands. Half tile, made by cutting whole tile longitudinally, and used where the roof butts against a vertical surface.

Extrusive. A term applied to those igneous rocks which have cooled after reaching the surface.

False cleavage. Very fine plications, seen on the cleavage surfaces of slates.

Fault. A slipping of rock masses along a fracture. Faults may occur in any kind of rock.

Felsite. A compact, fine-grained, light-colored volcanic rock of the same mineral composition as rhyolite or trachyte, whose mineral grains are too small to be recognized by the naked eye.

Feldspar. A name applied to a group of minerals having slightly different physical properties, and which are silicates of aluminum, with potassium, sodium and calcium. Thus orthoclase is a silicate of aluminum and potassium, while plagioclase is a silicate of aluminum with calcium or sodium or both. They have a pronounced cleavage and a hardness of 6. Color generally pink or white. Very abundant in igneous and some metamorphic rocks and rare in sandstones.

Ferruginous. Containing iron oxide.

Ferro-magnesian. A term often applied to the dark silicates found in igneous rocks, and which contain both iron oxide and magnesia.

Finial. Ornamental pieces of burned clay used for finishing off the joining of the ridge line with the hips, ridge line at gables, or top of a tower.

Fire brick. One made of fire clay, and capable of standing a high degree of heat (not less than 2700° F.).

Fire clay. One capable of standing a high temperature.

Fireproofing. A general name applied to those forms used in the construction of floor arches, partitions, etc., for fireproof buildings.

Fire shrinkage. The decrease in volume which a clay shows in burning.

Fissility. The tendency which some rocks show of separating into thin laminæ.

Flagstone. A term applied especially to sandstones which split naturally into thin slabs suitable for flagging.

Flashed brick. This term includes those brick which have had their edges darkened by special treatment in firing.

Flint. This is practically the same as chert, which see.

Flue linings. Pipe of cylindrical or rectangular cross section used for lining flues. Usually made of a low-grade fire clay.

Flue tops. A form of burned clay ware, often of ornamental character, placed on the top of chimney flues.

Flow structure. A streaked or banded structure shown by many igneous rocks and caused by a flowing movement of the rock while soft.

Foliated. See *Schistose.*

Forest marble. An argillaceous limestone in which the coloring matter is so distributed as to resemble forests.

Freestone. A stone that works easily or freely in any direction. It is applied especially to sandstones and limestones.

Frog. See *Key.*

Furring brick. Hollow brick for lining or furring the inside of a wall. Usually of common brick size, with surface grooved to take plaster.

Gabbro. A granular igneous rock, consisting chiefly of pyroxene and feldspar. The former may predominate to such an extent as to give the stone a black color.

Gable rake tile. The full-flanged tile used at the verge of open gables.

Garnet. A mineral which is a silicate of alumina, lime, iron or magnesia. Its hardness is 6–7, color often red, and grains frequently rounded.

Gneiss. A metamorphic rock, having the minerals arranged in more or less massive bands or layers. It is most commonly of the same composition as granite and might then be called a granite gneiss. Other types, however, are known, as *syenite-gneiss*, *diorite-gneiss*, etc.

Gneissic. Having a structure resembling that of gneiss (q. v.).

Graduated tile. Roofing tile which are required for covering curved surfaces such as a round tower, circular bays and other circular roofs.

Grain. A term used to indicate the second best direction of splitting. In granite it is usually at right angles to the rift; in slates it forms an angle to the cleavage. The term is also used to refer to the texture of a rock.

Granite. A plutonic igneous rock, usually even granular, of either fine or coarse grain. It is composed essentially of quartz and orthoclase feldspar, and one or more minerals of the mica, amphibole or pyroxene series.

Granite-porphyry. A rock of porphyritic texture and of the same mineral composition as granite.

Granitoid. Having a texture like granite.

Granodiorite. A diorite (q. v.), carrying a considerable percentage of quartz.

Graywacke. A sandstone of compact character, composed of grains of quartz, feldspar and argillaceous matter.

Greenstone. An indefinite term often applied to many dark igneous rocks of a green color, the latter being due often to chlorite. The term greenstone is applied to gabbro and basalt, diabase and diorite.

Grit. A sharp, gritty sandstone, especially one used as a whetstone.

Grog. Ground up pieces of burned clay or brick, added to the raw clay mixture for the purpose of decreasing the shrinkage and density of the burned ware.

Hardway. A direction of splitting at right angles to rift and grain. Same as *Cut-off.*

Harvard brick. A term originally applied to clear, red, common brick, which were overburned, and especially so on one end or side, so that these harder burned parts were bluish black. The name is more loosely used nowadays.

Header. A brick or stone laid with its greatest length at right angles to the surface of the wall.

Heading. A term sometimes used in quarrying to apply to a collection of close joints.

Hematite. A mineral which chemically consists of iron oxide (Fe_2O_3). Its powder is red.

Hip and ridge angle. A piece of roofing tile required where a hip starts from a ridge.

Hip-roll. A tile used for covering the hips on roofs, and which in cross section may show either roll or an angle.

Hip roll starter. A closed hip piece of roofing tile used at the lower end of a hip roll.

Hip tile. Tile which run up against a hip stringer.

Holocrystalline. A term applied to igneous rocks, which are usually crystalline.

Hollow blocks. These are hollow shapes, larger than common brick, usually of rectangular form, and having some cross webs. Used in exterior walls and also partitions.

Hollow brick. Brick molded with hollow spaces in them. They are usually strengthened by cross webs.

Igneous rock. One which has formed by the cooling of a molten mass of rock.

Interlocking tile. Roofing tile having ridges and grooves which interlock when the tile are laid on the roof.

Intrusive rocks. A term applied to those igneous rocks which have solidified without reaching the surface. Their occurrence on the surface now is because the rocks which were above them have been worn away.

Iron pyrite. See *Pyrite.*

Joints. Fractures, often steeply inclined, which may occur in any kind of rock. They are usually arranged in one or more series, those of the same series being parallel. Horizontal joints in granites develop a sheeted structure.

Kaolin. A white residual clay (q. v.) used in the manufacture of wall tile, china and sanitary ware.

Key, Frog or Panel. A rectangular depression, in one or both flat sides of a brick.

Kiln white. A scum which originates in the burning of brick.

Knots. A term often used to apply to bunches or segregations of dark minerals found in granites and gneisses. Sometimes applied to concretions found in sedimentary rock.

Lava. A molten rock, especially one flowing out over the surface. The term is also applied to the solidified rock.

Ledge. This term is usually applied to one, or a group of several beds occurring in a quarry. Also a ridge of solid rock outcropping at the surface.

Lift. The name sometimes applied to joint planes which are approximately horizontal.

Limestone. The name properly belongs to rocks composed of lime carbonate. They grade into dolomites with an increase of magnesium carbonate. Intermediate types are spoken of as magnesian or dolomitic limestones. Clay and quartz are common impurities.

Limonite. The hydrous iron oxide commonly found in many rocks. It is usually of brownish color.

Liver rock. Merrill states that this term is applied to a variety of Ohio sandstone which breaks or cuts readily in one direction or another.

Lustre. The natural polish or reflection shown by the surface of some minerals. Different kinds are recognized, such as vitreous, pearly, greasy, silky, etc.

Magnetite. The magnetic iron oxide (Fe_3O_4). It may occur in the darker colored igneous rocks and slate, but usually in microscopic grains.

Marble. True marbles are crystalline limestones, formed by the metamorphism of either limestones proper or dolomite. In the trade the term is sometimes loosely used to apply to any limestone that will take a polish.

Matrix. Also called ground mass. It refers to the general body of the rock, which often has isolated crystals scattered through it.

Matt glaze. A dull glaze applied to some burned clay products.

Metamorphic rocks. Those derived from igneous or sedimentary rocks through the agency of heat, pressure, chemical action, or all three, acting on them when they are more or less deeply buried in the earth's crust.

Mexican tile. A term sometimes applied to roofing tile of semicircular cross section.

Mica. A group name of minerals which are silicates of alumina, together with potash, lithia, magnesia and iron. They show a perfect cleavage and split easily into thin elastic plates. See *Muscovite, Biotite, Phlogopite.*

Micaceous sandstone. One containing numerous scales of mica.

Mission tile. A name sometimes applied to roofing tile of semicircular cross section.

Mitered tile. Roofing tile that are cut off obliquely, so as to fit in upright work, such as dormer corners. It also includes pieces flanged at right angles so as to cover such corners.

Molded brick. A term sometimes used for soft-mud brick.

Monolith. A single piece of stone.

Monzonite. A rock of intermediate mineral composition between a diorite and syenite.

Norman tile. Brick having the dimensions 12 by 2¼ to 2½ by 4 inches.

Obsidian. A volcanic glass, usually of acidic character.

Olivine. The common species is a silicate of magnesia, often of green, glassy character, and with a hardness of 6–17. It is a constituent chiefly of the darker igneous rocks such as basalt, diabase and gabbro.

Onyx. True onyx is a stone resembling agate, made up of layers of silica of different colors. The ornamental onyx or onyx marble is a carbonate of lime deposit, often colored by iron.

Oölitic. Made up of very small rounded concretions, having the appearance of fish roe.

Ophitic. A term relating to texture, consisting of interlacing lath-shaped crystals of feldspar whose interspaces are chiefly filled by pyroxene of later growth.

Orbicular granite. A granite containing numerous rounded segregations of minerals, chiefly dark silicates.

Ornamental brick. A somewhat broad term applied to front brick which are either of some form other than that of a rectangular prism, or which have the surface ornamented with some form of design.

Pale brick. Brick which are underburned.

Panel. See *Key.*

Paving brick. Vitrified brick used for paving purposes.

Pegmatite. A coarse-grained phase of granite. It often occurs as dikes or lenses in granites or metamorphic rocks.

Peridotite. A granular intrusive igneous rock composed of olivine and pyroxene without feldspar.

Phenocryst. Isolated or individual crystals, usually visible to the naked eye, which are embedded in a finer grained ground mass of igneous rock.

Phlogopite. A nearly colorless mica, resembling muscovite, which is not uncommon in crystalline limestones and serpentines.

Phyllite. A metamorphic rock intermediate between a slate and schist.

Pipe clay. A loosely used term applied to smooth, plastic clays, but specifically referring to clays for making sewer pipe.

Pipe press. The name commonly applied to the machine used for molding sewer pipe.

Pisolitic. Made up of rounded concretions of about the size of a pea.

Plagioclase. A collective name to include the lime-soda feldspars. See *Feldspar.*

Plasticity. The property possessed by clay of forming a plastic mass when mixed with water.

Platting. Brick laid flatwise on top of a scove kiln to keep in the heat.

Plutonic. A term referring to those igneous rocks which have cooled some distance below the surface and show usually a granitic texture.

Pompeiian brick. A loosely used term, but it is probably most frequently applied to bricks 12 by 1½ by 4 inches in size, of medium dark shade, with a brownish body covered with iron spots.

Porphyritic. A structure found in igneous rocks, indicating the presence of individual crystals (phenocrysts) in a finer grained ground mass.

Post. A mass of slate traversed by so many joints as to be useless.

Pressed brick. A loosely used term, applied to smooth-faced brick, commonly employed for fronts.

Pudding stone. See *Conglomerate.*

Pugging. Same as *Tempering.*

Pug mill. A machine for mixing or tempering wet clay.

Pumice. A name applied to a light, porous mass of volcanic glass.

Pyrite. A sulphide of iron (FeS_2) easily recognized by its yellow color and metallic lustre. It weathers to limonite. A not uncommon but undesirable constituent of many rocks.

Pyroxene. Includes several mineral species of the same general composition as amphibole, but differing in crystal form. Its hardness is usually 5 to 6. In small grains often indistinguishable from amphibole.

Quarry water. The water found in the pores of stone when first quarried.

Quartz. Chemically this is silica. It has a hardness of 7, glassy lustre, conchoidal fracture and no cleavage. It is a common constituent of many igneous rocks and sandstones.

Quartz monzonite. An igneous rock of granitic texture, containing quartz with orthoclase and plagioclase in about equal proportions.

Quartz porphyry. A porphyritic rock having the same mineral composition as granite, and with quartz occurring as a phenocryst.

Quartzite. A hard, siliceous rock, usually of metamorphic character and differing from sandstone in being harder and denser.

Repressed brick. Bricks which have been put through a second pressing machine after molding, to improve their shape, etc.

Residual clay. One formed by the decay of rock in place. This type is abundant in the southern states.

Rhyolite. A volcanic rock of the same general mineralogical composition as granite, but which usually shows a porphyritic texture. It may be quite porous.

Ribbons. Bands which show on the cleavage surface of the slate and indicate lines of bedding.

Ridge roll. A curved piece for covering ridge of roof laid with roofing tile.

Ridge tile. A roofing tile having the upper half flattened to a plane, and used at the roof ridge. It is covered by a finishing tile.

Ridge T. Used in roof tiling to indicate a trimming piece for use at the intersection of two ridges.

Ridging. See *Cresting.*

Rift. A microscopic cleavage in granite, which greatly aids in the quarrying of this stone.

Ring pit. A circular pit in which there revolves a large wheel; used for tempering clay.

Rock-face brick. Those with surface chiseled to imitate cut stone.

Roman tile or brick. Brick usually either dry pressed or stiff-mud repressed, and 12 by 1½ by 4 inches in size. The term is not always very definitely used.

Roofing tile. Burned-clay tile used for covering roofing.

Run. A term indicating the course of the rift.

Saccharoidal. A texture or grain like that of loaf sugar.

Salmon brick. See *Pale brick.*

Salt glaze. A glaze seen on sewer pipe and some kinds of stoneware, produced by placing salt in the kiln fires during burning.

Sandstone. A sedimentary rock, normally composed chiefly of sand grains.

Sap. An iron discoloration along joint surfaces in rocks.

Schist. A metamorphic rock made up chiefly of scaly mineral particles, like mica, which are arranged in a more or less parallel position and hence give the rock an irregular foliated or laminated structure.

Schistose. Having the structure of a schist.

Scove kiln. A temporary kiln, often used for burning common brick.

Sculp. The breaking of slate preparatory to splitting. It is usually done along the grain.

Seam. Same as *Joint.*

Sedimentary rocks. Those usually deposited under water, and having a stratified structure.

Selenite. A transparent crystalline variety of gypsum.

Semi-dry-press process. Practically the same as dry press, but clay may be slightly moister.

Sericite. A term applied to fine-grained, fibrous, white mica or muscovite.

Serpentine. A mineral composed of hydrous silicate of magnesia. The same name is applied to rocks made up chiefly of this mineral.

Settle. A term used to indicate the amount of vertical fire shrinkage that takes place in a kiln full of bricks.

Sewer brick. A general term applied to those common brick which are burned so hard as to have little or no absorption. They are, therefore, adapted for use as sewer linings.

Shale. A consolidated clay.

Shaly. A term applied to thinly bedded rocks, which break up into thin layers like shale.

Sheet quarry. A term often used in granite quarrying, to designate a quarry having strong horizontal joints and few vertical ones.

Shelly. Same as *Shaly.*

Shingle tile. A flat form of roofing tile.

Shrinkage. The decrease in volume which clays undergo in drying and burning.

Siding tile. Any roofing tile employed for upright work.

Siliceous. Containing appreciable silica as an impurity; for example, a siliceous limestone.

Slate. A metamorphic rock derived usually from shale and clay. It generally has a well-developed cleavage.

Slickensides. Polished and grooved surfaces, caused by one mass of rock in the earth's crust sliding past another, as happens in faulting.

Slip clay. An easily fusible clay, sometimes used to make a natural glaze on the surface of clay wares.

Slip glaze. One produced with slip clay (q. v.).

Slop brick. A name sometimes applied to soft-mud brick.

Soak pit. A pit in which wet clay is allowed to soak preparatory to molding.

Soft-mud process. A method of molding brick, by forcing clay into wooden molds.

Spanish tile. Roofing tile having an S-shaped cross section.

Specific gravity. The weight of a substance, as compared with an equal volume of distilled water.

Stalactite. A carbonate of lime deposit formed on the roof of limestone caves.

Stalagmite. A carbonate of lime deposit built up, usually in columnar forms, on the floor of caves.

Starter. See *Eave tile.*

Stiff-mud process. A plastic method of molding brick by forcing the clay through a die.

Stock brick. The better or selected bricks of a kiln.

Stratified rocks. Those rocks which occur in layers or beds and are of sedimentary origin.

Stretcher. A brick or stone laid with its length parallel to the face of the wall.

Strike. A term applied to stratified or metamorphic rocks to indicate the direction in which the tilted beds extend.

Stripping. Worthless material which has to be removed in quarrying.

Syenite. An igneous rock closely allied to granite, but differing from it in not containing quartz.

Syenite porphyry. A rock of porphyritic texture and same mineral composition as syenite.

Syncline. A trough-like fold.

Talc. A hydrous silicate of alumina, magnesia and iron. Hardness 1, feel greasy, and structure usually foliated. *Soapstone* is a massive impure form of talc, of no value as a building stone, but used for table tops, sinks, tubs, etc.

Tapestry brick. These are brick made by the stiff-mud process and having all surfaces roughened by wire cutting. Much used now for exteriors.

Tempering. The process of mixing clays preparatory to molding them.

Terra-cotta clay. A loose term that might include any clay used in the manufacture of terra cotta.

Terra-cotta lumber. A name applied to fireproofing shapes, which are very porous and somewhat soft.

Toe nails. Defined by Dale as "Curved joints intersecting the sheet structure, in most cases striking with the sheets, in some differing from them in strike 45 degrees or more."

Trachyte. A volcanic rock having the same mineral composition as syenite.

Trap. A name often applied to diabase and sometimes to basalt.

Travertine. A calcareous rock, deposited by spring or swamp waters. It is usually very porous.

Tremolite. A variety of amphibole (q. v.) found as an injurious impurity in some magnesian marbles.

Updraft kiln. One in which the heat enters the kiln chamber from the bottom and passes up through the ware.

Valley tile. Roofing tile made to fit in the valley of a roof.

Verde antique. A green rock, usually a mixture of serpentine and calcite.

Vesicular. See *Cellular.*

Volcanic ash. A deposit of loose, fine-grained volcanic glass ejected during volcanic eruptions. In its consolidated form it may be used for building stone.

Volcanic tuff. A deposit of volcanic ash which has become consolidated.

Volcanic rocks. Those igneous rocks which have reached the surface before cooling and solidifying.

Weathering. The breaking down of a rock when exposed to the action of weathering agents.

Whitewash. A white scum of soluble sulphates which accumulates on the surface of a brick or other clay product during or after manufacture.

Wall white. A white scum that appears on bricks after they are set in the wall.

INDEX

A.

Abrasive action of wind on stone, 70.
Abrasive resistance of, building stone, 70.
  slate, 230.
Absorption of, brick, 296.
  building stone, 44.
  floor tile, 366.
  limestones, 181.
  marbles, 201.
  roofing tile, 355.
  sandstones, 163.
Absorption test of brick, 296.
Acids, effect on weathering of stone, 85.
Adams County, Ill., 191.
Addison, Me., granite described, 109, 111.
Æolian marble, 213.
Air brick, defined, 259.
Alabama, granites of, 155.
  limestones of, 190.
  marbles of, 223.
  sandstones of, 170.
Alabama-Iris marble, 223.
Alabama-Sunset marble, 223.
Alabaster, defined, 10.
Alfred, Me., 111.
Amberg, Wis., granite described, 100, 157.
American Pavonazzo marble, 213.
  yellow Pavonazzo marble, 214.
Amherst, O., 173.
Amphibole, defined, 9.
Analyses of, clay, 258.
  limestones, 183.
  sandstones, 164.
Andesite in, Colorado, 161.
  Oregon, 161.
Aragonite, defined, 10.
Arbuckle Mountains, Okla., granites described, 159.
Arch brick, defined, 259.
Architectural terra cotta (see *Terra Cotta*).
Arizona, marbles of, 223.
  onyx marbles, 250.
  opal marble, 223.
  Pavonazzo marble, 224.
Arkansas, sandstones of, 176.
  slates of, 241.
  syenites described, 159.
  tests of slate from, 233.
Arkins, Colo., 177.
Arkose, defined, 29, 165.
Arvonia, Va., 241.
Ash, volcanic, 17.
Ashlar brick, defined, 259.
Athenian Green serpentine, 249.
Auburn, N. H., granite described, 112.
Augite, defined, 9.
Ausable Forks, N. Y., granite, 137.
Austin, Tex., 197.
  chalk, 197.
Avondale, Pa., 216.

B.

Bangor, Pa., 238, 241.
Barleyville, Me., 111.
Barre, Vt., granite described, 105, 116.
Basalt, in Oregon, 161.
  characters of, 24.
  porphyry, defined, 24.
Bate or false cleavage, defined, 226.
Bathylith, defined, 17.
Bayfield, Wis., 175.
Becket, Mass., 100.
Bedding, defined, 32.
  effect of, on quarrying, 32.
Bedford, Indiana, limestone, 191.
Beebe, cited, 298, 301, 309.
Belfast, Me., 111.
Belfast, Pa., 241.

Bellingham, Wash., 177.
Belleville, N. J., 168.
Bellvue, Colo., 177.
Berea, O., sandstone, 170.
Berea, O., 173.
Berlin, Wis., granite described, 100, 156.
Bethel, Vt., granite described, 116.
Bibb County, Ala., 190.
Biddeford, Me., 110.
Biotite, defined, 8.
Black granites, defined, 99.
Black Island, Me., 110.
Blue Hill, Me., 106, 110, 111.
Black marble, 216.
Blue Hill, Me., uses of granite from, 110.
Bluestone, defined, 165.
  in New York, 168.
  in Pennsylvania, 169.
Book tiles, defined, 333.
Bosses, defined, 17.
Bowling Green, Ky., 192.
Bradbury, Me., 111.
Brandon, Vt., 202.
  Italian marble, 207.
Branford, Conn., 100.
  township, Conn., granite described, 131.
Branner, J. C., cited, 176.
Brecciated structure, in marbles, 198.
Brick, building, raw materials used, 263.
    specifications for testing, 307.
  burning of, 279.
  comparison of different processes, 283.
  drying of, 276.
  kinds of, 259.
  methods of manufacture, 264.
  repressing of, 276.
  requisite qualities of, 314.
  scumming of, 312.
  testing of, 284.
  kilns, 279.
Brickotta, defined, 317.
Bridgeport, Wis., 195.
Broad Creek, Md., 249.
Brocadillo marble, 207.
Brookline, N. H., 111.
Brookville, Me., uses of granite from, 110.
Brownstone, defined, 165.
  in New Jersey, 168.
Brunswick, Me., 111.
Buckley, E. R., cited, 40, 43, 50, 51, 52, 55, 79, 94, 95, 155, 192.
Building stone, abrasive resistance of, 70.
    work of wind on, 80.
  absorption of, 44.
  chemical composition of, 75.
  color, 37.
  color, change in, 38.
  contraction of, 69.
  crushing strength of, 44.
  decomposition on weathering, 81.
  discoloration, 73.
  disintegration of, 76.
  effect of acid gases on, 74.
  effect of carbonic acid gas on, 74.
  effect of careless quarrying, 80.
  effect of freezing on, 79.
  effect of plants on, 80.
  effect of water on, 81.
  effect of temperature changes on, 76.
  expansion of, 69.
  fire resistance of, 55.
  frost resistance of, 54.
  hardening on exposure, 85.
  hardness of, 36.
  life of, 86.
  literature on, 87.
  permanent swelling, 69.
  polish of, 40.
  porosity of, 40.
  properties of, 36.
  quarry water in, 44.
  sap of, 87.
  soluble salts in, 85.
  texture of, 36.
  transverse strength of, 51.
  weathering of, 75.
Burnet County, Tex., 100, 160.
Byram, N. J., 168.

C.

Cabot, Vt., 116.
Calais, Me., 111.
Calais, Vt., 116.

Calcareous tufa, defined, 30.
Calcite, effect of, in building stones, 10.
in slate, 226.
properties of, 10.
Calc sinter, defined, 184.
Calhoun County, Ala., 190, 223.
Calico marble, 217.
California, granites of, 161.
marbles of, 224.
onyx marbles, 250.
sandstones of, 177.
serpentine, 249.
slates of, 242.
Canaan, N. H., 111.
Cannelton, Ind., 174.
Canyon City, Colo., 177.
Carbon, effect of, on clay, 257.
in marble, 198.
Carbonic acid gas, effect, of, on building stone, 74.
test, of building stone, 75.
Cardiff, Md., 241.
Carrara marble, texture, 36.
Carroll County, Ill., 174.
Carthage, Mo., 196, 223.
Castle Rock, Colo., 160.
Chalk, defined, 30, 183.
Champlain marbles, 214.
Chapman, Pa., 241.
Charlotte, N. C., 150.
Chazy, N. Y., 216.
Chemical composition of, building stone, 75.
granite, 95.
Chemical Composition (see also *Analyses*).
Cherokee, Ala., 170.
Cherokee County, N. C., 217.
Cherokee marbles, 218.
Chert, defined, 7.
in limestones, 181.
Chester, Mass., granite, 120, 125.
Chester, N. J., 168.
Chimney rock, 191.
Chlorite, defined, 11.
Cipolino marble, weathering of, 87.
Clark's Island, Me., uses of granite from, 110, 111.
Classification of granites, 95.
Connecticut, 133.
Maine, 110.
Massachusetts, 125.
New Hampshire, 113.
Clay, analyses of, 258.
chemical properties, 256.
color after burning, 257.
in slate, 229.
physical properties of, 253.
properties of, 253.
Cleavability of slate, 229.
Cleavage, of minerals, defined, 6.
of rocks, defined, 30.
Clinker brick, defined, 259.
Coal Measures, sandstones, Alabama, 170.
Indiana, 173, 174.
Michigan, 174.
Pennsylvania, 169.
Cockeysville, Md., 216.
Colbert County, Ala., 190.
Cold Springs, Okla., 159.
Colorado, andesite in, 161.
gneisses, 160.
granites described, 160.
limestones of, 197.
marbles of, 223.
rhyolite in, 160.
sandstones of, 176.
Color, building stone, cause of, 37.
change of, 38.
variation in, 38.
Color of, building stone, 37.
sandstones, 163.
slate, 229.
Columbia, S. C., granite described, 153.
Columbia Listavena marble, 214.
Columbus, Mont., 176.
Colusa County, Calif., 177.
Common brick, requisite qualities of, 314.
Compass brick, defined, 260.
Concord, N. H., granite described, 111.
Conglomerate, characters of, 29.
Connecticut, granites of, 128.
marbles of, 215.
sandstones of, 166.

Continuous kilns, 280.
Contraction of building stone, 69.
Conway, N. H., granite described, 112.
Conyers, Ga., granites, 154.
Cook County, Ill., 191.
Coosa County, Alabama, 223.
Coquina, defined, 30, 183.
  occurrence, 191.
Cordilleran region, granites of, 160.
  limestones of, 197.
Cornwall, Mo., 158.
Corona, Calif., 161.
Corrodibility of slate, 230.
Cotopaxi, Colo., 160.
Cotton-rock, Mo., 196.
Cranberry Lake, N. J., granite described, 138.
Creole marble, 218.
Cresting tile, 361.
Crosby, W. O., cited, 244.
Cross fracture, of slate, 229.
Crotch Island, Me., 110, 111.
  granite described, 106.
Crushing test of brick, 284.
Crushing strength of, brick, wet and dry compared, 294.
  building stone, 44.
  floor tile, 370.
  granites, 94
  limestones, 181.
  marbles, 201.
  sandstones, 163.
Crystal form of minerals, 6.
Cullman, Ala., 170.
Cut-off, defined, 96.
  in granite, 96.
Cuyahoga County, O., 173.

D.

Dale, T. N., cited, 94, 96, 99, 111, 113, 116, 132, 136, 233.
Danielsville, Pa., 241.
Dark Florence marble, 213.
Dark Vein Esperanza marble, 213.
Deer Isle, Me., 110.
Dedham, Me., 111.
De Kalb County, Ala., 190.
Del Norte, Colo., 161.
Derby, Vt., 116.
Dikes, defined, 17.
  in granite, 99.
Dillon, Mont., 160.
Diorite, characters of, 23.
  porphyry, defined, 24.
Discoloration of building stone, 73.
Discoloration test, building stone, 73.
Distribution of sandstones, 166.
Dix Island, Me., uses of granite from, 110.
Dolomite, defined, 183.
  properties of, 10.
  as building stones, 178.
  properties of (see under *Limestones*).
Dolomitic limestone, defined, 184.
Dorset Dark Green Vein marble, 207.
Dorset Mountain, Vt., 202.
Dorset white marble, 208.
Douty, cited, 298, 301, 309.
Dover, N. J., granite described, 138.
Dry-press brick, properties of, 275.
Dry-press process, 275.
Dummerston, Vt., 116.
Dunn's Mountain, N. C., 149.
Dunnville, Wis., 174.
Dutch brick, defined, 260.

E.

East Bangor, Pa., 241.
East Canaan, Conn., 215.
East Cleveland, O., 173.
East Longmeadow, Mass., 167.
Easton, Pa., 244.
Eave tile, 361.
Edgecomb County, N. C., 146.
Edwards limestone, Texas, 197.
Efflorescence of brick, 312.
Elasticity of, granites, 94.
  slate, 230.
Elberton, Ga., granite described, 154.
Eldorado County, Calif., 242.
Electrical resistance of slate, 230.
Ellicott City, Md., granite described 141.
Enameled brick, defined, 259.
  requisite qualities, 317.

Essex County, N. Y., 244.
Etowah County, Ala., 190.
  marble, 218.
Euclid, O., 173.
  bluestone, 173.
Expansion of building stone, 69.
Expansion coefficient of brick, 305.

F.

Face brick, defined, 250.
Fairburn, Ga., granites, 154.
Fairfield County, S. C., 100.
Fall River, Mass., 120.
False cleavage in slate, defined, 226.
Feldspar, properties of, 7.
Felsite, characters of, 24.
Finials, 361.
Fire brick, defined, 260.
Fireproofing, defined, 333.
  fire tests of, 346.
  properties of, 334.
  specifications for, 345.
  tests of, 341.
Fire resistance of, building stone, 55.
  granites, 95.
  limestones, 181.
  sandstones, 165.
  terra cotta, 328.
Fire tests of, brick, 302.
  fireproofing, 346.
Fisk Black marble, 213.
Fitzwilliam, N. H., granite described, 111, 112.
Flagstones, Colorado, 177.
  defined, 166.
  New Jersey, 168.
  New York, 168.
Flashed brick, defined, 260.
Flexibility of granite, 94.
Flint, defined, 7.
  in limestone, 196.
Floor tile, manufacture of, 366.
  properties of, 365.
  testing of, 369.
Florence marble, 208.
Florentine blue marble, 213.
Florida, limestones of, 191.
Foerster, cited, 43.
Fourche Mountain, Ark., 159.
Fox Island, Me., granite described, 109.
Franklin County, Ala., 190.
Frankfort, Me., 111.
Fredericksburg, Va., granite described, 145.
Fredericktown, Mo., 158.
Freeport, Me., 111.
Freestone, defined, 166.
Freezing, effect of, on building stone, 79.
Freitag, cited, 302, 328, 331, 337, 338, 339, 347.
Frenchtown, Md., granite gneiss, 142.
Front brick, defined, 259.
Frost resistance of building stone, 54.
Frost test of, brick, 305.
  building stone, artificial, 54.
  natural, 54.
Fryeburg, Me., 111.
Furring blocks defined, 333.
  sizes made, 338.
Furring brick, defined, 260.
Fusibility of clay, 255.

G.

Gabbro, characters of, 23.
  of California, 161.
  of North Carolina, 150.
Garnet, properties of, 11.
Gary, cited, 70, 73.
Genessee, Wis., 105.
Georgia, granites of, 154.
  marbles of, 218.
  serpentine of, 249.
  slates of, 241.
German Valley, N. J., granite described, 138.
Gladson, W. M., cited, 231.
Glazed brick, defined, 259.
Glens Falls, N. Y., 216.
Gneiss, defined, 31.
Gneisses, distribution in United States, 105.
  of Maryland, 142.
  of New Jersey, 137.
Gouverneur, N. Y., 216.

Graduated roofing tile, 361.
Grady, R. F., cited, 324.
Grain in slate, defined, 226.
Grain of granite, 96.
Granite as a rock, properties of, 18.
Granite City, Okla., 100, 159.
Granite diorite, defined, 23.
Granite Heights, Wis., 100.
Granite porphyry, defined, 23.
Granites, black, 99.
characteristics of, 94.
chemical composition of, 95.
classification of, 95.
crushing strength, 94.
cut-off in, 96.
dikes in, 99.
distribution in United States, 105.
elasticity of, 94.
expansion of, 95.
fire resistance of, 95.
flexibility of, 94.
grain of, 96.
inclusions in, 99.
joints in, 96.
knots in, 96.
market price of, 136.
mineral impurities in, 94.
of Alabama, 155,
of California, 161.
of Colorado, 160.
of Connecticut, 128.
classification of, 133.
of Cordilleran area, 160.
of eastern belt, 105.
of Georgia, 154.
of Maine, classification of, 110.
of Maine, 106.
of Maryland, 138.
of Massachusetts, 120.
of Minnesota, 157.
of Missouri, 158.
of Montana, 160.
of New Hampshire, 111.
classification of, 113.
of New Jersey, 137.
of New York, 137.
of North Carolina, 145.
of Oklahoma, 159.
Granites, of Rhode Island, 128.
of South Carolina, 150.
of Texas, 160.
of Vermont, 116.
of Virginia, 142.
of Wisconsin, 155.
porosity of, 95.
porphyritic, North Carolina, 149.
rift of, 96.
run of, 96.
sheets in, 96.
specific gravity of, 94.
structure of, 96.
tests of, 99.
uses of, 105.
weight per cubic yard, 94.
Graniteville, Mo., granite described, 100, 158.
Granville, N. Y., 238.
Graywacke, defined, 166.
Gregory, H. E., cited, 132.
Greenbrier County, W. Va., 190.
Green Island, Me., 110.
Greenville, Ga., granite, 154.
Greenwich, Conn., granite described, 131.
Greystone, N. C., granite described, 149.
Groton, Conn., granite described, 116, 132.
Guilford, Md., granite described, 110, 141.
Gypsum, properties of, 10.

H.

Hagerstown, Md., 190.
Hallowell, Me., granite described, 106, 111.
Hampton, N. Y., 238.
Hannibal, Mo., 196.
Hardening of building stone, 85.
Hardness, of building stone, 36.
of sandstones, 162.
Hardness scale of minerals, 6.
Hardness, test of, 37.
Hard vein slate, 238.
Pennsylvania, 238.

Hardway, defined, 96.
Hardwick, Vt., granite described, 116.
Hartland, Me., 111.
Hawes, G., cited, 57.
Heath Springs, S. C., granite described, 153.
Helderberg limestone, N. Y., 189.
Helena, Mont., 160.
Henry County, Ill., 174.
Hermann, cited, 40.
Hermon, Me., 111.
Hip rolls, 361.
Hip roll starters, 361.
Hip tile, 360.
Hollow blocks, defined, 333.
  sizes of, 339.
  tests of, 340.
Hollow brick, defined, 260, 333.
Hollow ware, manufacture of, 333.
  raw materials used, 333.
Holly Springs, Ga., 249.
Hornblende, properties of, 9.
Hudson River Bluestone, 168.
Hummelstown, Pa., 169.
Humphrey, R. L., cited, 56.
Hunterdon County, N. J., 168.
Hurricane Island, Me., granite described, 109.

I.

Igneous rocks, defined, 13.
  classification of, 18.
  distribution in United States, 105.
  texture of, 17.
  used for building, 93.
Illinois, limestones of, 191.
  sandstones, 174.
Inclusions in granite, 99.
Index, Wash., 100.
Indiana, limestones of, 191.
  sandstones of, 173.
Interlocking tile, defined, 351.
Inyo County, Calif., 224.
Iowa, limestones of, 196.
Iron oxide, effect on clay, 256.
Iron pyrite (see *Pyrite*).
Italio marble, 208.

J.

Jacobsville, Mich., 174.
Jasper, Ala., 179.
  marble, 214.
Jay, Me., 111.
Jefferson City, Mo., 190.
Jefferson County, Ala., 195.
Jointing, defined, 52.
  effect of, on quarrying, 52.
  in granite, 96.
Joints in slate, 220.
Joliet, Ill., 191.
Jones, J. C., cited, 298, 300.
Jonesboro, Me., granite described, 110.
Jonesport, Me., 110.
Julien, A. A., cited, 80.

K.

Kaiser, E., cited, 85.
Kankakee County, Ill., 191.
Kansas, limestones of, 196.
Kasota, Minn., 195.
Keeler, Calif., 224.
Kennebunkport, Me., 110.
Kentucky, limestones of, 192.
Kettle River sandstone, Minnesota, 175.
Key West, Fla., 191.
Kibbe, Mass., 167.
Kirby, Vt., 116.
Kittatinny Mountain, N. J., 168.
Knob Lick, Mo., granite described, 158.
Knobstone sandstone, Indiana, 173.
Knots, defined, 96.
Knowles, Wis., 195.

L.

Lancaster County, Pa., 189.
Landscape Green serpentine, 249.
Lannon, Wis., 195.
Lawrence County, Ind., 191.
Lawrenceville, Ga., granites, 154.
Lawrenceville, N. J., 168.
Lebanon, N. H., 111.
Lee, Mass., 215.
Lehigh County, Pa., 238.

Lemont, Ill., 191.
Lenox Library, N. Y. City, 87.
Lepanto marble, 216.
Lewis and Clarke County, Mont., 160.
Lexington, Ga., 154.
Lexington, N. C., 150.
Life of building stone, 86.
Light Cloud Rutland marble, 207.
Lime, effect on clay, 256.
  in slate, 229.
Limestone, fossiliferous, defined, 183.
  hydraulic, defined, 183.
Limestones, absorption of, 181.
  as building stone, 178.
  characters of, 29.
  chemical composition of, 183.
  color of, 178.
  crushing strength of, 181.
  distribution in United States, 184.
  fire resistance of, 181.
  hardness of, 178.
  of Alabama, 190.
  of Cordilleran region, 197.
  of Florida, 191.
  of Illinois, 191.
  of Indiana, 191.
  of Iowa, 196.
  of Kansas, 196.
  of Kentucky, 192.
  of Maryland, 190.
  of Minnesota, 195.
  of Missouri, 196.
  of New Jersey, 189.
  of New York, 189.
  of Ohio, 192.
  of Pennsylvania, 189.
  of Texas, 197.
  of Virginia, 190.
  of West Virginia, 190.
  of Wisconsin, 192.
  tests of, 181.
  texture of, 178.
  varieties of, 183.
  weathering qualities, 181.
Limonite, properties of, 12.
Lincoln, Me., 111.
Lincoln County, Me., 106.
Listavena marble, 208.
Lithographic limestone, defined, 183.
Lithonia, Ga., granites, 100, 154.
Little Falls, N. J., 168.
Little Rock, Ark., 100, 159.
Llano County, Tex., 100, 160.
Lockport, N. Y., 167, 189.
Long Cove, Me., 111.
Lower Carboniferous limestone, Missouri, 196.
Lower Magnesian limestone, Wisconsin, 192, 195.
Luquer, L. McI., cited, 54.
Lustre, of minerals, defined, 6.
Lyonnaise marble, 214.

M.

Machias, Me., uses of granite from, 110.
Mäckler, cited, 313.
Madison County, Ill., 191.
Magnesian limestone, defined, 184.
Magnetite, properties of, 12.
Maiden Rock, Wis., 195.
Maine, granites described, 106.
  slates of, 237.
Manitou stone, Colo., 177.
Mankato, Minn., 195.
Mansfield sandstone, Ind., 173.
Marble, defined, 184.
Marblehead, Wis., 195.
Marble, absorption of, 201.
  characters of, 31.
  color of, 198.
  mineral composition, 197.
  properties of, 197.
  strength of, 201.
  texture of, 198.
  uses of, 201.
  weathering qualities of, 201.
Marbles, distribution in United States, 202.
  of Alabama, 223.
  of Arizona, 223.
  of California, 224.
  of Colorado, 223.
  of Connecticut, 215.
  of Georgia, 218.
  of Maryland, 216.

Marbles, of Massachusetts, 215.
of Missouri, 223.
of New York, 215.
of North Carolina, 217.
of Pennsylvania, 216.
of Tennessee, 218.
of Virginia, 217.
of Vermont, 202.
Marcasite, defined, 12.
in slate, 230.
Marini, V. G., cited, 345.
Marlboro Granite, N. H., 111, 113.
Marquette, Mich., 174.
Marshall County, Ala., 190.
Marshfield, Me., 110.
Martinsburg, W. Va., 241.
Martinsville, N. J., 168.
Maryland, gneisses of, 142.
granites described, 138.
limestones of, 190.
marbles of, 216.
sandstones of, 169.
serpentine of, 249.
slates of, 241.
Mascoma, N. H., granite described, 113.
Massachusetts, granites, classification of, 125.
described, 120.
marbles of, 215.
sandstone of, 166.
serpentine of, 244.
Matthews, E. B., cited, 170.
McCourt, W. E., cited, 56.
Medina sandstone, 167.
Mena, Ark., 242.
Menominee, Wis., 174.
Merrill, G. P., cited, 9, 49, 54, 70, 87, 95, 166, 177, 241, 244.
Metamorphic rocks, characters of, 30.
Mexican tile, defined, 350.
Miami, Mo., 176.
Mica, effect of, on building stone, 8.
in marble, 197.
Micas, properties of, 8.
Michelot, cited, 51.
Michigan, sandstones of, 174.
Middlebury, Vt., 202.
Milford, Mass., granite described, 120.
Milford, N. H., granite described, 111, 112.
Millbridge, Me., 111.
Millstone, Conn., granite described, 131.
Mineral impurities in granite, 94.
Minerals, form of, 6.
hardness of, 6.
in building stones, 3.
physical properties of, 5.
Minnesota, granites of, 157.
limestones of, 195.
sandstones of, 175.
Mission tile, defined, 350.
Missouri, granites of, 158.
limestones of, 196.
marbles of, 223.
sandstones of, 176.
Modern Spanish tile defined, 350.
Mohegan granite, N. Y., 137.
Monroe County, Ind., 191.
Monson, Me., 237.
Montana, granites of, 160.
sandstones of, 176.
volcanic ash in, 160.
Montello, Wis., granite described, 100, 155.
Montgomery County, Ark., 241.
Montgomery County, Pa., 189.
Monzonite, defined, 23.
Moose Island, Me., 110.
Moriah, N. Y., 244.
Mountain white marble, 208.
Mount Airy, N. C., 100, 149.
Mount Ascutney, Vt., 116.
Mount Desert, Me., 110, 111.
Muscovite, defined, 8.

N.

Nash County, N. C., 146.
Newark, Vt., 116.
New Bedford, Mass., 120.
Newburgh, O., 173.
New Hampshire, granites of, described, 111.

New Jersey, granites of, 137.
limestones of, 189.
sandstones of, 168.
serpentine of, 244.
slates of, 238.
Newman, Ga., granite, 154.
Newton, N. J., 238.
New York, granites of, 137.
limestones of, 189.
marbles of, 215.
sandstones of, 167.
serpentine of, 244.
slates of, 238.
New Ulm, Minn., 176.
Niagara limestone in, Illinois, 191.
New York, 189.
Wisconsin, 192, 195.
Normal tile, defined, 350.
Norman tile, defined, 260.
Norridgewock, Me., 110, 111.
Northampton County, Pa., 238.
North Carolina, granites of, 145.
marbles of, 217.
North Jay, Me., granite described, 105, 106.

O.

Oglesby, Ga., granite described, 154.
Ohio, limestones of, 192.
sandstones of, 170.
Oklahoma, granites described, 159.
Old Spanish tile, defined, 350.
Olive marble, 214.
Olivine, properties of, 11.
Olivo marble, 214.
Onyx, defined, 30.
marble, defined, 249.
marbles, foreign, 250.
in United States, 250.
marble, origin of, 249.
properties of, 250.
Oolitic limestone, Alabama, 190.
defined, 184.
Florida, 191.
Indiana, 191.
Kentucky, 192.
West Virginia, 190.
Ophicalcite, defined, 243.
Ophiolite, defined, 243.
Oregon, andesite in, 161.
basalt of, 161.
Oriental Verde marble, 214.
Ornamental brick, defined, 260.
Orthoclase, properties of, 8.
Ortonville, Minn., granite, 157.
Owen County, Indiana, 191.
Oxford, Me., 111.

P.

Pale brick, defined, 260.
Paterson, N. J., 168.
Paving brick, defined, 260.
Peach Bottom slate, 241.
Peekskill, N. Y., granite, 137.
Pegmatite, defined, 18.
Pen Argyl, Pa., 241.
Pennsylvania, limestones of, 189.
marbles of, 216.
sandstones of, 169.
slates of, 238.
serpentine of, 244.
Penobscot, Me., 106.
Penobscot County, Me., 106.
Penryn, Calif., 161.
Peridotite, characters of, 23.
Permanent swelling of building stone, 69.
Permeability of brick, 301.
Petersburg, Va., granite described, 142.
Phenix, Mo., 196.
Phillipsburg, N. J., 244.
Phlogopite, defined, 8.
Phyllite, defined, 31.
Pickens County, Georgia, 218.
Picton, N. Y., granite described, 137.
Pirsson, L. V., cited, 17.
Pittsburg, Pa., 169.
Pittsford, Vt., 202.
Pittsford-Italian marble, 213.
Pittsford Valley marble, 213.
Plagioclase feldspars, properties of, 7.
Plasticity of clay, 253.
Plateau white marble, 213.
Plattsburg, N. Y., 216.
Pleasant River, Me., use of granite from, 110.

Pleasantville, N. Y., 215.
Plutonic rocks, defined, 17.
Pocahontas marble, 223.
Point of Rocks, Md., 216.
Polish of building stone, 40.
Polk County, Ark., 241.
Pompeiian brick, defined, 260.
Pompton, N. J., granite described, 138.
Porosity of, brick, 298.
  building stone, 40.
  granite, 95.
Porphyritic, defined, 17.
  granite, North Carolina, 149.
Port Deposit, Md., granite described, 141.
Port Deposit, Md., 100.
Port Henry, N. Y., 244.
Post, defined, 226.
Potsdam, N. Y., 167.
Potsdam sandstone, Mich., 174.
  Wisconsin, 174, 175.
Pownal, Me., 111.
Pressed brick, defined, 260.
  requisite qualities of, 314.
Princeton, N. J., 168.
Purdue, A. H., cited, 233.
Pyrite, as coloring agent, in building stone, 39.
  effect of, on building stone, 12.
  in building stone, 82.
  in limestones, 181.
  in marble, 198.
  in slate, 226.
  properties of, 12.
Pyroxene, properties of, 9.
Pyroxenite, characters of, 23.

Q.

Quarry tile, 360.
Quarry water, 86.
  effect of, 44.
  in building stone, 44.
Quartz, in marbles, 198.
  in slates, 226.
  properties of, 7.
Quartzite, characters of, 30.
  defined, 166.
Quartzites, distribution of, 166.
Quincy, Mass., granite described, 105, 120, 125.

R.

Raleigh, N. C., granite described, 149.
Randolph, Vt., 116.
Raymond, Calif., 101.
Redbeach, Me., 111.
  granite described, 109.
Red Beds, Colorado, sandstone from, 177.
Redstone granite, N. H., described, 112.
Repressing brick, 270.
Rhode Island, granites of, described, 128.
Rhyolite of Colorado, 160.
Ribbons in slate, defined, 226.
Richmond, Va., granite described, 142.
Ridge tile, 361.
Ries, H., cited, 253.
Rift, 96.
Ridgefield, N. J., 168.
Rion, S. C., granite described, 153.
Riverside, Calif., 161.
Riverside County, Calif., 161.
Rochester, N. Y., 167, 189.
Rochester, Vt., 116.
Rock face brick, defined, 260.
Rocklin, Calif., 161.
Rockmart, Ga., 241.
Rockport, Mass., granite described, 100, 120.
Rocks, classification of, 12.
  definition of, 12.
  igneous, defined, 12.
  plutonic, defined, 17.
  volcanic, defined, 17.
Rockville, Minn., 100.
Rockwood County, Ala., 190.
Rocky Butte, Ore., 161.
Roman tile (brick), defined, 260.
  (roofing), defined, 350.
Roofing tile, absorption of, 355.
  glazing, value of, 356.
  kinds defined, 349.
  manufacture of, 352.
  materials used, 352.

Roofing tile, porosity of, 352.
requisite characters, 359.
special shapes, 360.
testing of, 359.
Rosaro marble, 214.
Rosiwal, cited, 37.
Rowan County, N. C., granite described, 149.
Roxbury, Vt., 244.
Royal Blue marble, 213.
Royal Red marble, 214.
Royal Washington serpentine, 249.
Rubio marble, 214.
Run, defined, 96.
Ryegate, Vt., 116.

S.

Sainte Genevieve, Mo., 196.
Salida, Colo., 160.
Salisbury, N. C., 149.
Salmon brick, defined, 263.
Sandstones, absorption of, 163.
analyses of, 164.
argillaceous, defined, 29.
arkose, defined, 29.
calcareous, defined, 165.
characters of, 29.
ferruginous, defined, 166.
micaceous, 29.
as building stones, 162.
cement of, 162.
color of, 163.
crushing strength of, 163.
distribution of, 166.
fire resistance of, 165.
hardness of, 162.
Sandstones of, Alabama, 170.
Arkansas, 176.
Atlantic States, 167.
California, 177.
Central States, 170.
Colorado, 176.
Connecticut, 166.
Illinois, 174.
Indiana, 173.
Maryland, 169.
Massachusetts, 166.
Sandstones of, Michigan, 174.
Minnesota, 175.
Missouri, 176.
Montana, 176.
New England States, 166.
New Jersey, 168.
New York, 167.
Ohio, 170.
Pennsylvania, 169.
Virginia, 170.
Washington, 177.
Western States, 176.
West Virginia, 170.
Wisconsin, 174.
texture of, 162.
varieties of, 165.
weathering of, 165.
Sanitary ware, 388.
manufacture of, 388.
properties of, 388.
raw materials used, 388.
San José, Calif., 177.
Sap, in stone quarries, 87.
Schist, defined, 31.
varieties of, 31.
Scove kilns, 279.
Sculping of slate, 229.
Scumming of brick, 312.
Scum on terra cotta, 328.
Searsport, Me., 111.
Sedgwick, Me., 111.
Semi-dry-press-process, 275.
Seneca Creek, Md., 169.
Seneca Red-stone, Maryland, 169.
Sericite, defined, 8.
Serpentine, as building stone, 243.
distribution in United States, 243.
mineral impurities of, 243.
Serpentine of, California, 249.
Georgia, 249.
Massachusetts, 244.
Maryland, 249.
New Jersey, 244.
New York, 244.
Pennsylvania, 244.
Vermont, 244.
Washington, 249.
Serpentine, properties of, 11.

Sewer blocks, 385.
Sewer brick, defined, 263.
Sewer pipe, dimensions of, 373.
manufacture of, 372.
raw materials used, 372.
requisite qualities, 374.
specifications of, 377.
Shakes, defined, 96.
Shale, characters of, 29.
Shattuck Mountain, Me., 110.
Sheets, defined, 96.
Shelby County, Ala., 190.
Shenandoah limestone, Maryland, 190.
Shingle tile, defined, 349.
Shrinkage of clay, 254.
Slate, characters of, 30.
quarrying, 236.
Slatedale, Pa., 241.
Slates, classification of, 225.
distribution in United States, 236.
for building purposes, 225.
Slates of, Arkansas, 241.
Georgia, 241.
California, 242.
Maine, 237.
Maryland, 241.
New Jersey, 238.
New York, 238.
Pennsylvania, 238.
Vermont, 237.
Virginia, 241.
West Virginia, 241.
Slate, properties of, 226.
price of, 235.
properties of, 229.
tests of, 233.
Slatington, Pa., 238, 241.
Slip cleavage in slate, defined, 226.
Slop brick, defined, 263.
Snowflake granite, N. H., 113.
Soapstone, defined, 11.
Soft-mud bricks, properties of, 266.
Soft-mud process, 265.
Soft-vein slate, Pennsylvania, 238.
Solid-porcelain sanitary ware, 388.
Soluble salts, in brick, 312.
in building stone, 39.
in terra cotta, 328.
Sonorousness of slate, 229.
South Berwick, Me., 111.
South Brookville, Me., 110.
South Carolina, granites of, 150.
South Dover, N. Y., 215.
Southern marble, 218.
South Thomaston, Me., 110.
Sparta, Ga., granite described, 154.
Specifications, for sewer pipe, 377.
Iowa, for sewer pipe, 379.
Specific gravity of, brick, 309.
building stone, 40.
granites, 94.
slate, 230.
Spruce Head, Me., 111.
St. Augustine, Fla., 181, 191.
St. Clair County, Ala., 190.
St. Clair County, Ill., 174.
St. Cloud, Minn., granite, 100, 157.
St. George, Me., 111.
St. Louis, Mo., 196.
St. Peter's sandstone, Wisconsin, 174.
St. Stephen's limestone, Alabama, 191.
Statuary marble, 213.
Steatite, properties of, 11.
Stevens County, Wash., 249.
Stiff-mud brick, properties of, 275.
Stiff-mud process, 269.
S-tile, defined, 350.
Stockton, N. J., 168.
Stone Mountain, Ga., granite described, 155.
Stonington, Me., uses of granite from, 110.
Stony Creek, Conn., granite described, 131.
Stout, Colo., 177.
Stratification (see *Bedding*), 32.
Strength of slate, 230.
Stratified rocks, defined, 24.
Structural features of quarries, 31.
Sturgeon Bay, Wis., 195.
Sullivan, Me., 111.
Sulphur, effect on clay, 257.
Sulphuric acid gas, effect on building stone, 74.
Sulphurous acid gas, effect on building stone, 74.

Sussex County, N. J., 168, 189.
Sutherland Falls, marble, 208.
Swans Island, Me., 110.
Swanton, Vt., 202, 214.
Swanville, Me., 111.
Swain County, N. C., 217.
Syenite, characters of, 23.
  Arkansas, 159.
  Missouri, 100.
  porphyry, defined, 23.
Sylacauga, Ala., 223.

T.

Talc, properties of, 11.
Talladega County, Ala., 122, 190.
Tapestry brick, defined, 263.
Taylor's Mill, Ala., 223.
Temecula, Calif., 161.
Tenino sandstone, Washington, 177.
Tennessee, marbles of, 218.
Tensile strength of clay, 255.
Terra cotta, architectural, defined, 320.
  fire-resisting properties, 328.
  manufacture of, 320.
  properties of, 324.
  raw materials used, 320.
  scum, 328.
  testing of, 324.
  lumber, defined, 333.
Testing brick, methods used, 284.
Tests for brick scum, 313.
Tests of, fire-proofing, 341.
  hollow blocks, 340.
  roofing tile, 359.
  sandstone, 164.
  sewer pipe, 383.
  slate, 233, 234.
Tests, proposed, for sewer pipe, 382.
Texas, granites of, 160.
  limestones of, 197.
  Maryland, 216.
Texas Creek, Colo., 160.
Texture of, building stone, 36.
  sandstones, 162.
Topsham, Vt., 116.
Toughness of slate, 230.
Toula, cited, 37.
Tournaire, cited, 51.
Tower tile, 361.
Transverse strength of building stone, 51.
  effect of heat on, 53.
Transverse test of brick, 294.
Trap Rock, New Jersey, 138.
  in Virginia, 145.
Travertine, defined, 30, 184.
  worked in Italy, 184.
Tremolite, in marble, 198.
  properties of, 9.
Trempeleau, Wis., 195.
Trenton limestone, Ala., 190.
  Missouri, 196.
  New York, 189.
  Wisconsin, 192, 195.
Troy, N. H., granite described, 111, 112.
True Blue marble, 213.
Tuckahoe, N. Y., 215.
Tufa, calcareous, defined, 30.
Tuff, defined, 17.
Tuscaloosa, Ala., 170.

U.

Unakite, in Virginia, 145.

V.

Valley tile, 360.
Verdolite, 244.
Verdoso marble, 214.
Verdura marble, 214.
Vermont, granites described, 116.
  marbles, varieties of, 207.
  marbles of, 202.
  serpentine of, 244.
  slate of, 237.
Veins in slate, 226.
Victorville, Calif., 249.
Vinalhaven, Me., granite described, 109, 110, 111.
Virginia, granites of, 142.
  limestones of, 190.
  marbles of, 217.
  sandstones of, 170.
  slates of, 241.
Vitreous sanitary ware, 388.

Volcanic ash, as a building stone, 93.
Montana, 160.
Volcanic rocks, defined, 17.

W.

Waldoboro, Me., 111.
Wall tile, manufacture, 363.
tests of, 369.
Wallingford, Vt., 202.
Warren, Wis., granite described, 156.
Warren County, Ind., 173.
New Jersey, 168, 189.
Warrensburg, Mo., 176.
Warsaw Bluestone, N. Y., 168.
Washburn, Wis., 175.
Washington County, Me., 106.
New York, 237, 238.
Washington monument, marble in, 216.
Washington, sandstones of, 177.
serpentine of, 249.
Watchung, N. J., 168.
Water, effect on building stone, 81.
Waterford township, Conn., granite described, 131.
Watson, T. L., cited, 50, 146.
Waupaca, Wis., granite described, 156.
Wausau, Wis., granite described, 157.
Wauwatosa, Wis., 195.
Weathering of, building stone, 75.
limestones, 181.
marbles, 201.
sandstones, 165.
Weisner sandstone, Ala., 170.
Welch's Spur, Mont., 160.
Wells, Me., 110.
West Chester, Pa., 244.
Westerly, R. I., granite described, 100, 105, 128.
West Monson, Me., 237.
West Rutland, Vt., 202, 207.
West Virginia, limestones of, 190.
sandstones of, 170.
slates of, 241.
Wheeler, H. A., cited, 352.
Whitefield, Me., 111.
Whitehall, N. Y., 238.
Wichita Mountains, Oklahoma, granites described, 159.
Wilburtha, N. J., 168.
Will County, Ill., 191.
Williams, J. F., cited, 37.
Wilson County, N. C., 146.
Windsor, Vt., granite described, 116.
Wisconsin, granites of, 155.
limestones of, 192.
sandstones of, 174.
Wise, N. C., granite described, 149.
Woodbury, Vt., granite described, 119.
Woodbury, Vt., 116.
Woodstock, Me., 111.
Woodstock, Md., granite described, 141.
Woolson, I. H., cited, 303, 346.
Worthy, Ind., 174.
Wyoming Valley stone, Pennsylvania, 169.

Y.

York County, Me., 106.
Yule Creek, Colo., 223.